Exploring opportunities for mitigating the ecological impacts of current and future mountain pine beetle outbreaks through improved planning: A focus on northeastern British Columbia

Brad Seely, John Nelson, Pierre Vernier, Ralph Wells, and Arnold Moy

Mountain Pine Beetle Working Paper 2008-08

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Abstract

The primary response to the present mountain pine beetle (MPB) epidemic has focused on salvaging beetle-killed wood while it remains economically viable, and developing methods for reducing the spread of the current epidemic and the risk of future outbreaks. While these are important and necessary activities, we cannot afford to pursue these objectives without a careful consideration of their ecological implications. Mountain pine beetle salvage activities at the stand and landscape scale can have substantial ecological impacts including: reduction in the habitat supply of forest-dependent songbirds, loss of mature habitat, shifts in seral-stage patch size distributions, and changes in stand dynamics. The massive scale of the current outbreak has pushed the boundaries of our understanding from previous outbreaks to the point that some of the core assumptions around sustainable economic and ecological forecasts now must be re-examined.

Using an established modelling framework, we conducted a scenario analysis exercise designed to explore opportunities to mitigate the ecological and economic impacts of MPB salvage for two possible outbreak severity levels in Canfor's Tree Farm License (TFL) 48 in northeastern BC. The following questions were addressed:

1. What are the potential short and long-term impacts of different levels of MPB attack for indicators of sustainable forest management in northeastern BC?

2. Assuming a reduction in landscape-level ecological and economic stocks, what management options are available that will maintain a profitable harvesting profile while sustaining ecological indicators?

Results from the analysis were evaluated in the context of a range of ecological and economic indicators.

Keywords: mountain pine beetle, stand dynamics modelling, habitat modelling, decision support tools, ecological indicators

Résumé

La première intervention visant à contrer l'épidémie actuelle de dendroctone du pin ponderosa (DPP) avait pour objectif de sauver le bois détruit par le dendroctone tant qu'il était exploitable et de développer des méthodes pour atténuer sa propagation et le risque de pullulations futures. Même si ce sont des activités importantes et nécessaires, nous ne pouvons pas poursuivre ces objectifs sans étudier minutieusement leurs répercussions sur l'écosystème. Les activités de préservation du dendroctone du pin ponderosa, à l'échelle des peuplements et du territoire, peuvent avoir des répercussions considérables sur l'écosystème : diminution du nombre d'habitats pour les oiseaux chanteurs dépendant de la forêt, perte d'habitats matures, changement dans le stade de succession, les dimensions des parcelles et la dynamique des peuplements. L'étendue de l'actuel pullulement a tellement repoussé les limites de notre compréhension, par rapport aux pullulements antérieurs, que nous devons maintenant réexaminer certaines des hypothèses fondamentales concernant les prévisions économiques et écologiques durables.

À l'aide d'un cadre de modélisation établi, nous avons fait un exercice d'analyse de scénario. Le but de l'exercice était d'explorer les possibilités d'atténuer les répercussions écologiques et économiques, associées à la préservation du DDP, pour deux degrés de gravité possibles de pullulement, à la concession de ferme forestière 48, à Canfor, dans le nord-est de la Colombie-Britannique. Nous avons répondu aux deux questions ci-après.

1. Quelles sont les répercussions possibles à court et à long terme des différents degrés d'attaque du DPP sur les indicateurs de gestion durable de la forêt dans le nord-est de la Colombie-Britannique?

2. En supposant que les réserves écologiques et économiques baissent au niveau du territoire, quelles sont les solutions de gestion qui nous permettraient d'assurer la rentabilité de la récolte tout en maintenant les indicateurs écologiques?

Nous avons évalué les résultats de l'analyse compte tenu de divers indicateurs écologiques et économiques.

Mots-clés : dendroctone du pin ponderosa, modélisation des dynamiques de peuplement, modélisation de l'habitat, outils d'aide à la décision, indicateurs écologiques.

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1 Introduction

The primary response to the present mountain pine beetle (MPB) epidemic has focused on 1) salvaging beetle-killed wood while it remains economically viable, 2) planning to mitigate economic impacts associated with the loss of fibre in the near- and long-term, and 3) developing silvicultural and landscape management methods for reducing the spread of the current epidemic and the risk of future outbreaks. While these are important and necessary activities, we cannot afford to pursue these objectives without a careful consideration of their ecological implications. Mountain pine beetle (MPB) salvage activities at the stand and landscape scale can have substantial ecological impacts including (but not limited to): reduction in the habitat supply of forest-dependent songbirds, loss of mature pine habitat, shifts in seral-stage patch size distributions, and changes in stand dynamics (including ecosystem productivity and the rates of recovery of key habitat elements). The massive scale of the current outbreak has pushed the boundaries of our understanding from previous outbreaks and current spread projections to the point that some of the core assumptions around sustainable economic and ecological forecasts now must be re-examined.

The fundamental dynamics driving post-attack stand development and the potential influence of salvage activities are illustrated in Figure 1. To achieve broader forest-level management objectives, the impact of specific salvage activities on stand-level dynamics must be evaluated in a landscape context. To address these complex issues adequately, we require decision-support systems which allow us to examine the potential short- and long-term consequences of MPB management alternatives on both economic and ecological indicators of sustainable forest management (SFM) at varying spatial scales. Stand-level models underlying such decision support systems must be capable of projecting patterns of stand development following varying levels of attack and associated salvage/rehab systems, and following silviculture interventions designed to reduce the susceptibility of existing stands to future attack. Furthermore, they must be able to track the development of stand attributes associated with both economic and ecological indicators of SFM. At the landscape scale, models must consider harvest flow, access management, and the influence of MBP management activities on landscape patterns associated with the distribution and abundance of forest-dwelling species.

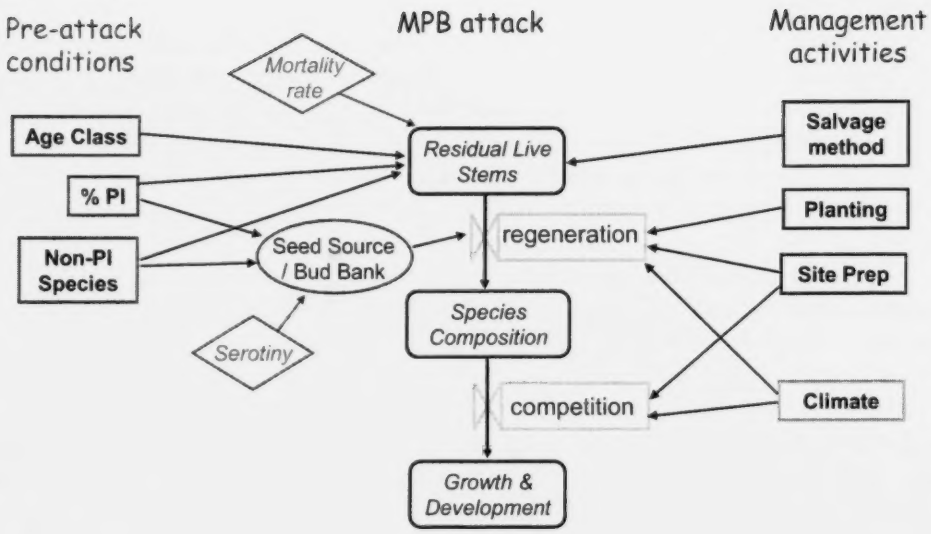

Figure 1. Factors affecting the growth and development of stands following MPB attack. Developmental trajectories can be influenced through management/salvage activities.

To examine alternative approaches to mitigating the ecological impact of salvage activity while maintaining economic viability, we simulated two possible outbreak severity levels in Canfor's Tree Farm License (TFL) 48 in northeastern BC, using a modelling framework established at the University of British Columbia (see Seely et al. 2004). This area is presently in the early stages of MPB attack and includes reasonably large areas of mature pine forests that are susceptible to attack to varying degrees (Coops et al. 2006). Results from the modelling framework were evaluated in the context of a range of ecological and economic indicators.

1.1 Project Objectives

The overarching objective of this work is to use an existing modelling framework and associated methodologies developed at the University of British Columbia (UBC) to conduct a scenario analysis exercise designed to explore opportunities to mitigate the ecological and economic impacts of the seemingly inevitable MPB outbreak in the landscapes of northeastern BC, previously unaffected by MPB. The following questions were addressed:

1. What are the potential short- and long-term impacts of different levels of MPB attack for indicators of sustainable forest management (SFM) in northeastern BC?

2. Assuming a reduction in landscape-level ecological and economic stocks, what management options are available that will maintain a profitable harvesting profile while sustaining ecological indicators?

Specific project objectives included the following:

1) Use the ecologically based FORECAST model to evaluate patterns in stand dynamics and rates of recovery of key stand attributes following MPB attack with and without associated salvage/rehab treatments for representative stand types.
2) Identify a suite of appropriate ecological and economic indicators for examining the impacts of MPB attack.
3) Develop/adapt existing models that relate selected ecological indicators to stand and landscape attributes so that these can be projected over time using our forest simulation tools.
4) Simulate MPB attack scenarios: two outbreak levels (low and high) for the target landscapes.
5) Use MPB attack scenarios as a baseline to examine stand and landscape scale opportunities for mitigating ecological impacts while meeting economic objectives.

2 Material and Methods

2.1 Description of Study Area

The study area for the modelling work was the Tree Farm License (TFL) 48, managed by Canadian Forest Products Ltd. It is located in northeastern British Columbia near Chetwynd and spans from the east slopes of the Rocky Mountains down into the foothills and eastward into the southeastern edge of the Boreal Plains (Fig. 2). In addition to fibre production, other important resource uses within TFL 48 include oil and gas exploration, trapping, hunting, motorized recreation and an evolving eco-tourism industry. Conflicts between public groups interested in access to remote sites and those interested in wilderness are common. Tree Farm License 48 represents an area of approximately 651,000 ha in size of which about 54% (353,000 ha) is defined as being part of the timber harvesting land base (THLB). The primary forest types within the area can be divided into three main regions based on climate and species composition. Specific BEC subzones within each region are listed in parentheses. The three main forest regions include 1) the Wet Mountain area (ESSFwc) consisting primarily of high elevation forests dominated by Engelmann spruce and subalpine fir, 2) the Boreal Foothills area consisting of drier mid-slope and foothills forests dominated by hybrid spruce, lodgepole pine and aspen, and 3) the Boreal Plains area dominated by mixedwood stands of white spruce, aspen and lodgepole pine (Fig. 3).

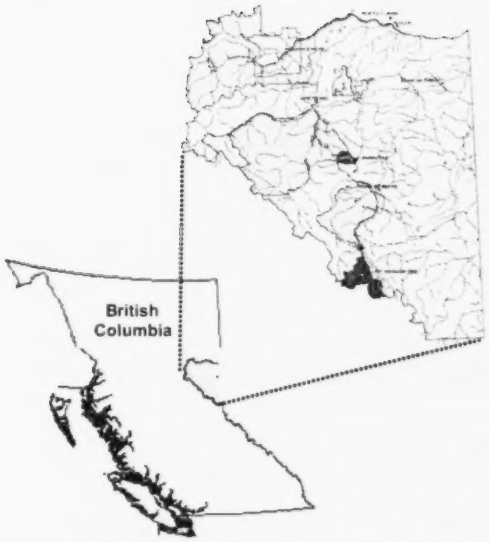

Figure 2. Illustration showing the location of the 651,000 ha study area within northeastern British Columbia.

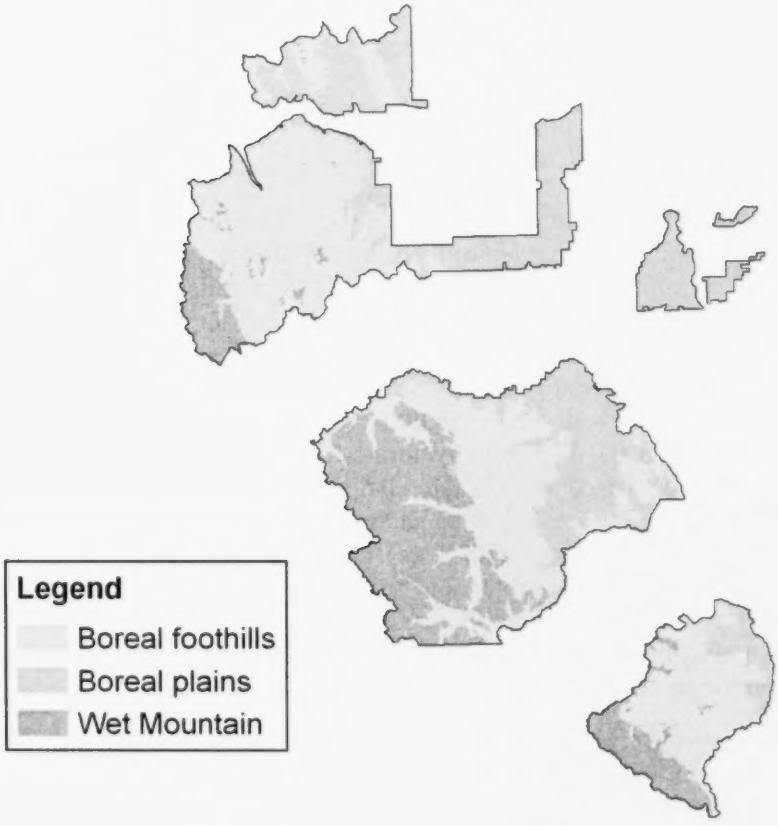

Figure 3. Map of the distribution of forest regions within TFL 48.

Wildfire is the dominant disturbance agent in TFL 48, with the exception of the Wet Mountain region in which stands are more often subject to endemic levels of various insects and diseases. The foothills region of TFL 48 down slope of the Rocky Mountains is dominated by large wildfires, resulting in large patches of even-aged forest with a significant component of lodgepole pine (Fig. 4). Fire control in this region may have slowed the natural disturbance rate, increasing the amount of mature to old forest in areas not subject to timber harvesting, and reducing large areas of fire-origin stands (Delong 1998). Like the foothills region, the Boreal Plains region to the east of the foothills is also dominated by fire and consequently has significant pine component.

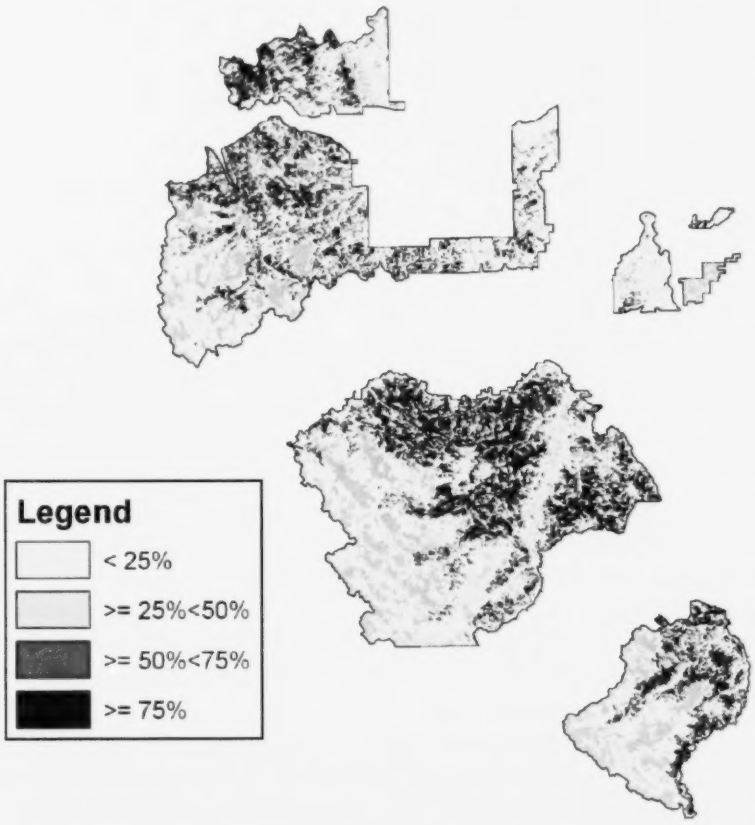

Figure 4. Map showing the forested area within TFL 48 divided into categories based on pine content (%).

2.2 Stand-level analysis

One of the main objectives of the project was to examine the potential to manipulate post-MPB-attack stand development trajectories of MPB-susceptible stands through the use of different salvage systems. Towards this end, the ecosystem-based FORECAST model (Kimmins et al., 1999) was employed to project post-attack stand development in forest types that varied in species composition, age at the time of attack, and intensity of MPB attack. In addition, the model was used to examine the degree to which different salvage and associated stand establishment options might influence the development of stand attributes related to ecological and economic indicators of sustainability.

2.2.1 Description of FORECAST Model

The model, FORECAST (Kimmins et al., 1999) is an ecosystem-based, stand-level, forest growth simulator. The model was designed to accommodate a wide variety of harvesting and silvicultural systems in order to compare and contrast their effect upon forest productivity, stand dynamics, and various biophysical indicators of non-timber values. The model uses a hybrid approach whereby local growth and yield data (often from locally calibrated empirical growth and yield models) are combined with other data to derive estimates of the rates of key ecosystem processes related to the productivity and resource requirements of selected species. It uses derived measures of decomposition, nutrient cycling, light competition, and other ecosystem properties to simulate forest growth and ecosystem dynamics under changing management and environmental conditions. Growth and yield in complex stands is based on a simulated partitioning of limited resources (light and nutrients) among species and age cohorts. The biological properties of individual species, as defined by the input data, determine their relative competitiveness for limited resources. The ability of FORECAST to project the development of stand attributes related to both timber and non-timber values in an integrated system provides a strong foundation for a trade-off analysis of alternative forest management strategies. The model has been shown to perform well in many different forest types and for a variety of management systems (e.g., Blanco et al., 2007; Seely et al., 2008; Bi et al., 2007; Welham et al., 2007). The calibration data sets employed for this study were developed as part of an earlier study in the same study area (Seely et al. 2004).

2.2.2 Application of FORECAST

A set of three different salvage/regenerations options was simulated in FORECAST for each MPB-susceptible stand type. The different salvage options included management designed to either: 1) enhance biodiversity, 2) increase productivity, or 3) reduce the risk of a future MPB outbreak (planting more non-pine species). An alternative option of leaving the attacked stand in an unsalvaged condition with no planting or rehabilitation

was also simulated for each stand type. Unsalvaged stands were regenerated based on natural regeneration that reflected the percent pine and other mature species at the time of MPB attack (Appendix 1). It was assumed that all stands were in an even-aged condition prior to MPB attack (e.g., no significant advanced regeneration that would be protected at harvest). A basic description of each of the three themes is provided below.

Biodiversity

- *Treatment*: The fundamental approach applied in the biodiversity salvage treatments was the retention of live trees (non-pine, usually greater than 60 years old, depending on the age class of the stand at the time of attack) for the preservation of some mature structure within the stand and for future recruitment of large snags and deadwood. Planting density was proportional to amount of retention. Regeneration species were based on the pre-salvage species distribution.
- *Application:* This treatment was applied to all attacked stand types with the exception of pure pine in which case a default clearcut salvage was applied.

Production

- *Treatment:* The objective of this theme was to facilitate the rapid regrowth of merchantable volume as soon as possible. The basic approach was to clearcut harvest and plant with 75% pine and 25% spruce and to fertilize.
- *Application:* This treatment was applied only to stands that were classified as being medium to high productivity prior to salvage (see Table A4). All other stands were salvaged using a default clearcut approach with planting and natural regeneration that reflected pre-salvage species composition.

Risk Reduction

- *Treatment:* The objective of this theme was to facilitate the regrowth of stands that would have a relatively low susceptibility to future MPB attack as the stand matures. This was achieved by planting no more than 25% pine in combination with other species based on pre-salvage species composition.
- *Application:* This treatment was applied only to stands that were classified as pine category 3 or 4 (> than 50% Pl, or >75% Pl) at the time of salvage. All other stands were salvaged using a default clearcut approach with planting and natural regeneration that reflected pre-salvage species composition.

2.2.3 Development of Analysis Units and Stand Attribute Database

In developing the analysis units for this project, an emphasis was placed on pine containing stands such that more detail was used in describing MPB-susceptible stand

types. The rationale for this was to allow for a more complete representation of the subtleties of post-attack stand developmental dynamics. The criteria defined in Table 1 were used to divide the forest inventory into appropriate analysis units described by a 5-6 digit code (salvaged stands have an extra digit). A detailed description of the analysis units including MPB attack severity, salvage and planting options, natural regeneration assumptions and stand transition pathways is provided in Appendix 1. A stand attribute database was generated including attribute tables for a 150-year time horizon (5- or 10-year time steps) for each of the analysis units described in Appendix 1. Attributes in the database include: merchantable volume by species, density by species, top height by species, snags (> 25 cm dbh) by species, logs (> 25cm dbh) by species, ecosystem carbon storage, and shrub cover (%).

Table 1. Criteria used to define the stand-level analysis units. To reduce the number of analysis units, age classes 3 & 4 have been combined in the database and are referred to as age class 3. Criteria used indicate susceptibility to MPB attack are shaded.

1	2	3[a]	4	5[b]	6[c]
Type	**Pine Category**	**Non-Pl Lead Species code**	**SQ**	**Age Class**	**Salvage Objective**
(1) Natural	(1) < 25%	(1) S*	(1) Poor	(1) < 40	(0) Default
(2) MPB attack	(2) >= 25% < 50%	(2) Bl	(2) Med-Good	(2) 40-80	(1) Biodiversity
(3) Managed	(3) >= 50% < 75%	(3) A* or E*		(3) > 80	(2) Productivity
	(4) >=75%	(5) A or E MXD			(3) Low Risk
		(6) S* MXC			

a – S* (spruce species), Bl (subalpine fir), A* or E* (deciduous leading, represented by aspen), A or E MXD (deciduous leading mixedwood), S* MXC (conifer leading mixedwood)

b – A value of 0 was assigned for pine category (1) polygons

c – Only assigned to managed stands

2.2.4 Development of Stand-level Indicators

A series of indicators were defined to facilitate an evaluation of individual stands and larger landscapes with respect to general measures of habitat suitability and economic value. Indicators of stand susceptibility to future MPB attack and ecosystem carbon storage were also included. To facilitate a direct trade-off analysis, all indicators were indexed to have values ranging from 0 to 1. All indicators were calculated based on the output of the FORECAST model for each analysis unit described in Appendix 1. A description of each indicator is provided in Table 2 below. The Shrub Cover index was designed to provide a measure of early seral habitat quality. It is sensitive to below-canopy light levels. In contrast, the Snag and Large Live Structure indices were developed to function as measures of mature forest conditions. Many forest planning models use age-based seral stage for this purpose. However, the uneven-aged stand conditions created by MPB attack and salvage systems that include retention of live structure are not well represented by an age-based approach. A better approach is to track stand attributes directly related to mature structure including large diameter snags and

live trees. The thresholds identified in Table 2 are based on our current understanding of mature habitat requirements, but could easily be modified to address changing habitat requirements. The Snag, Large Live Structure, and MPB Susceptibility Indices were calculated at both the stand and landscape scales (See Section 2.3.5). For the purposes of this analysis, the others were only calculated at the stand level.

In addition to the use of the aforementioned indicators, spatially explicit habitat suitability indices were derived and employed to facilitate evaluations of landscape pattern on habitat suitability for selected bird species (see Section 2.3.6).

Table 2. A description of the indexed stand-level indicators used for trade-off analysis.

Indicator	**Description**	**Threshold***
Shrub cover	Index of percent cover by shrubs	100%
All Snags	Index of snags (all species) greater than 25 cm dbh	25 snags ha^{-1}
Hardwood Snags	Index of hardwood snags greater than 25 cm dbh	25 snags ha^{-1}
Large Live Structure	Index of large live stems greater than 25 cm dbh	200 stems ha^{-1}
Merchantable Volume	Index of economic value based on 10 cm top diameter limit	540 m^3 ha^{-1}
MPB Susceptibility	Index of MPB susceptibility based on SSI (Shore and Safranyik 1992)	100
Ecosystem C Storage	Index of ecosystem carbon storage	320 T C ha^{-1}

*Threshold value used to calculate the indexed value. When the threshold is achieved the value =1, values < Threshold are scaled (0-1) by dividing the current value by the threshold value.

2.3 Landscape-Scale Analysis

2.3.1 Preparation of spatial data

The spatial database used for the landscape-scale analyses was created from Canfor's TFL 48 Management Plan 4 timber supply analysis resultant, natural disturbance and predictive ecosystem mapping (PEM) data (Schuetz 2005). These datasets were combined in a GIS by using a series of union operations. The resulting number of polygons were reduced by removing polygons less than or equal to 1 ha. Special attention was given to buffered linear features such as streams, roads and seismic lines. Within these features, polygons that were smaller than or equal to 0.25 ha were removed. Species and age information was added to the resultant by joining Rank 1 layer attributes from the 2004 VRI database.

The timber harvest landbase (THLB) for all scenarios was defined by excluding inoperable areas, non-contributing areas, riparian and water buffers, archaeological sites, protected areas, rare site series and parks. Analysis units were assigned to polygons within the spatial database based on the criteria outlined in Table 1. To facilitate the representation of the different levels of MPB attack, susceptible Pl stands were assigned to be attacked by the MPB using a semi-random approach in which stands from each pine category (see Table 1) were flagged as attacked until the desired level of attack was reached (50% for low and 100% for high). With the exception of the high level (100%) of attack, stands with higher pine contents had a higher probability of being flagged. Tables of polygons flagged for attacked were prepared to provide input to the ATLAS simulation model (Nelson 2003) for each level of attack (Section 2.3.3).

Input data maps for SIMFOR were created by rasterizing attributes within the spatial database. A cell size of 50 m was used to create the input maps for age, stand, disturbance, block and calculation. The age map was created using the current age of the landscape, which was the projected age in 2004. The stand map was created from the analysis units. The calculation map was created using the TFL 48 timber harvest landbase definition, where areas of THLB & NHLB were given values of 1 (calculation) and all other areas assigned to 0 (no calculation). The block map was created from the unique polygon identifier (AtlasId) in the spatial database.

2.3.2 Description of Landbase

The initial distribution of area among the different analysis units (described in Tables A1-A5) within the TFL 48 spatial dataset is summarized in Table 3. A total area of 204,491 hectares (41% of the total productive forest area) was classified as susceptible. A breakdown of the susceptible area into different categories of pine content and secondary leading species is shown in Table 4.

Table 3. A breakdown of the area within TFL 48 by analysis unit (AU) representing initial conditions. The amount of area in each AU within the THLB is also shown.

AU	Origin	Total (ha)	THLB (ha)	% of Total	% in THLB
11110	Natural	88,970	59,016	15.8%	66.3%
11120	Natural	19,753	15,016	3.5%	76.0%
11210	Natural	84,475	34,176	15.0%	40.5%
11310	Natural	63,051	35,640	11.2%	56.5%
11510	Natural	12,713	5,845	2.3%	46.0%
11610	Natural	11,135	8,154	2.0%	73.2%
12110	Natural	28,778	19,741	5.1%	68.6%
12120	Natural	10,271	8,289	1.8%	80.7%
12210	Natural	5,421	2,576	1.0%	47.5%
12310	Natural	9,869	4,207	1.7%	42.6%
13110	Natural	29,586	21,223	5.2%	71.7%
13120	Natural	22,152	18,826	3.9%	85.0%
13210	Natural	6,141	3,540	1.1%	57.6%
13310	Natural	5,738	3,059	1.0%	53.3%
13320	Natural	5,934	5,226	1.1%	88.1%
14110	Natural	37,936	28,121	6.7%	74.1%
14120	Natural	24,646	22,060	4.4%	89.5%
14210	Natural	4,495	3,094	0.8%	68.8%
14310	Natural	6,775	4,863	1.2%	71.8%
14320	Natural	6,751	6,209	1.2%	92.0%
311100	Managed	248	225	0.0%	90.8%
311200	Managed	3,286	3,139	0.6%	95.5%
312100	Managed	1,734	1,608	0.3%	92.7%
313100	Managed	1,644	1,225	0.3%	74.5%
315100	Managed	1,374	1,151	0.2%	83.8%
316100	Managed	2,518	2,410	0.4%	95.7%
321100	Managed	308	290	0.1%	94.0%
321200	Managed	1,138	1,083	0.2%	95.1%
322100	Managed	115	89	0.0%	77.9%
323100	Managed	134	127	0.0%	95.1%
331100	Managed	14	14	0.0%	100.0%
331200	Managed	327	311	0.1%	95.0%
low productivity forest types	Natural	66,738	32,389	11.8%	48.5%
Total		**564,165**	**352,940**	**100.0%**	**62.6%**

Table 4. Breakdown of total area susceptible* to MPB attack into categories based on percent pine and secondary species prior to attack.

Category	Total (ha)	THLB (ha)	% of Total	% In THLB
Pine Category (25-50% Pl)	54,339	34,812	26.6%	64.1%
Pine Category (50-75% Pl)	69,550	51,874	34.0%	74.6%
Pine Category (> 75% Pl)	80,602	64,347	39.4%	79.8%
Secondary species (Spruce)	153,369	118,260	75.0%	77.1%
Secondary species (Subalpine Fir)	16,058	9,209	7.9%	57.4%
Secondary species (Deciduous)	35,065	23,565	17.1%	67.2%
Total Susceptible	**204,491**	**151,033**	**100%**	**73.9%**
% of total productive forest	***41.1%***	***47.1%***		

* As specified in Table 1.

2.3.3 Scenario Development

The landscape-scale analysis was designed to incorporate stand management objectives within the context of different levels of MPB attack and different spatial salvage strategies at the landscape level. The two spatial salvage strategies investigated were: 1) an economic value-driven salvage that prioritizes the salvage of the most profitable stands first, and 2) a zone-guided salvage that also prioritizes the most profitable stands first, but also sets aside portions of the THLB as biodiversity zones where salvage harvests are not permitted. Table 5 summarizes the stand management objectives and landscape strategies that were used to define the scenarios modeled. In the upper portion of Table 5 (referred to as Phase 1), replications of the scenarios were made for two MPB attack levels (50% and 100% of susceptible stands) and two levels of salvage (100% – all attacked stands salvaged and Pine 3 – only stands with a pine category $\geq$ 3 salvaged). The initial set of scenarios in Phase 1 was designed to explore the consequences of attack levels, salvage intensity and stand management objectives over a wide range of assumptions.

Zoning Scenarios (Phase 2)

Using preliminary results from Phase 1 as a guide, a set of zoning scenarios were developed to investigate the efficacy of setting aside portions of the THLB to improve outcomes for biodiversity indicators while maintaining economic performance (Table 5). Two alternative zoning strategies were assessed. The first, entitled 'Hardwood' emphasized the removal of stands with high deciduous components (based on % volume) from the harvesting landbase. Mature hardwood stands were identified to be important for many of the evaluated bird species (see Sections 2.3.6 and 3.23). The second strategy entitled 'Diverse' was based on the assumption that it may be better to reserve a diverse

range of stand types within the THLB from harvesting. Two levels of THLB retention (10% and 20%) were evaluated for both strategies. In all cases the MPB attack level was high and salvage was limited to pine category ≥ 3 stands. In total, there are 12 economic value-driven salvage scenarios and four zone-guided salvage scenarios summarized in Table 5.

Table 5. Matrix of scenarios by stand management objective and landscape level strategy. The upper portion of the matrix (Phase 1) is repeated for two levels of MPB attack and two salvage intensities. The lower portion of the matrix (Phase 2) is repeated for two zoning strategies and two zoning intensities at the high MPB attack level and the Pine 3 salvage intensity.

	Spatial Salvage	**Stand management objective**		
		Biodiversity	**Productivity**	**Risk Reduction**
Landscape-level strategies	Economic Value-driven Salvage **Phase 1**	1. Spatial priority for salvage based on current value, Salvage with retention of mature structure. Replicated for 2 attack levels (High and Low) and 2 salvage strategies (100% PI and PI category 3 only). **Scenarios** (attack level - stand management objective - salvage intensity): **Hi-Bio-100** **Hi-Bio-Pine3** **Low-Bio-100** **LOW- Bio-Pine3**	2. Spatial priority for salvage based on current value, Salvage using clearcut and for eligible stands plant with 75% PI and fertilize. Replicated for 2 attack levels (High and Low) and 2 salvage strategies (100% PI and PI category 3 only). **Scenarios** (attack level - stand management objective - salvage intensity): **Hi-Prod-100** **Hi-Prod-Pine3** **Low-Prod-100** **Low-Prod-Pine3**	3. Spatial priority for salvage based on current value, Salvage using clearcut and plant with less than 25% PI. Replicated for 2 attack levels (High and Low) and 2 salvage strategies (100% PI and PI category 3 only). **Scenarios** (attack level - stand management objective - salvage intensity): **Hi-Risk-100** **Hi-Risk-Pine3** **Low-Risk-100** **Low-Risk-Pine3**
	Zone-guided Salvage **Phase 2**	4. Spatial priority based on zoning, No harvesting in *Biodiversity zones*, while in *Production zones* clearcut, plant with 75% PI and fertilize. Replicated for 2 zoning strategies (Hardwoods Zones and Diverse Species Zones) and for 2 zoning intensities (10% and 20% of THLB). **Scenarios** (attack level - stand management objective – zone –zone%): **Hi- Diverse-10%** **Hi- Diverse -20%** **Hi- Hardwood-10%** **Hi- Hardwood -20%**		

2.3.4 ATLAS Scenario Modelling

The ATLAS simulation model (Nelson 2003) was used to generate all harvest scenarios. The database used for the ATLAS modelling is described in Sections 2.3.1 and 2.3.2. All scenarios where projected for 245 years, using 2-year time steps during the salvage period (years 1-15) and 10-year time steps thereafter. The first harvest priority during the salvage period was to cut Pl category 3 and 4 stands first, and the second harvest priority was to harvest the most profitable of these stands first. Following the salvage period, the harvest priority was to cut the most profitable stands first. Profitability for all stands was calculated using the method described by Boyland et al. (2005), and unprofitable stands were not harvested in any scenario. The minimum harvest age of all stands was set to the age when each stand reached a merchantable volume of 200 m3/ha. Following the salvage harvest, previously attacked stands were re-assigned to new regeneration growth and yield curves according to the stand management objectives (Table A4).

In all scenarios, constraints were applied during the salvage period so that only attacked Pl stands were available for harvest. In most cases, other stands become available in year 25, but with Low_Bio_100 and Low_Bio_Pine3 they become available in year 12 and 10 respectively, because all salvaged stands have been harvested by that time. For the Pine3 salvage scenarios, all pine category 2 stands are prevented from harvest until Pine3+ stands are salvaged. In most cases category 2 stands become available in year 15, except for High_Bio_Pine3 and Low_Bio_Pine3, when they become available in year 12 and 10, respectively, because all pine category 3+ stands have been salvaged. In addition to these constraints that affect the availability of non-attacked stands, stand-level retention constraints were applied in all the BIO scenarios (Table A5).

The strategy for determining the harvest level was to get the highest, uniform flow during the salvage period (years 1-15), and then the highest long-term, uniform flow thereafter. In the case of the BIO runs, some unsusceptible and pine category 2 stands had to be released early to achieve the short-term harvest levels. For each scenario, results were recorded for the annual harvest (m3/year), harvest volume by stand type (m3/year), growing stock (m3), average profitability ($/m3) and the average length of active roads (km/year). The road network projected for TFL 48 (Seely et al., 2004) was used to model road network activity once the ATLAS harvest schedule was determined.

2.3.5 Landscape analysis of biodiversity and risk indicators

Landscape-scale trends biodiversity risk indicators were evaluated using SIMFOR, a spatially and temporally explicit projection tool (Wells and Moy 2002). It combines harvesting plans (Section 2.3.4) with projections of forest attribute development (Section 2.2.3) to calculate landscape pattern and metrics. When evaluating the implications of management for a large diverse landscape such as TFL 48, it is informative to report impacts on specific forest types or regions within the landbase to determine if they are being affected differently. To this end, trends in indicators were reported for three distinct forest strata (Table 6).

The SIMFOR model was used to calculate landscape metrics and pattern for six key management scenarios (HI-PROD-PINE3; HI-BIO-PINE3; DIVERSE ZONING - 10% and 20%; HARDWOOD ZONING - 10% and 20%) described in Table 5. These scenarios were selected as the best and most informative of all the scenarios based on preliminary results. Only the high MPB attack scenarios were included in the analysis as the low attack scenarios showed only modest impacts from MPB attack. The ATLAS harvest schedules and FORCAST stand-level projections of specific index values were projected for each scenario using the SIMFOR model.

Mean landscape index values were calculated for each stratum and for each simulation period, based on the values within associated raster grid cells with a resolution of 50 m.

Table 6. The different forest strata within the TFL 48 landbase defined for reporting management impacts on biodiversity and risk indicators.

Stratum	Criteria	AUs included*	Total Area (ha)	% in THLB
Pine Leading Conifer	> 50% Pl with S	x31xx, x41xx	118,815	78.5
High Elevation Spruce Balsam	S or Bl leading, < 50% Pl	xx2xx, x11xx, x21xx	249,077	59.1
Deciduous / Mixedwood	Dec leading or mixedwood	xx3xx, xx5xx, xx6xx	127,500	61.2

* Based on criteria outlined in Table 1.

2.3.6 Application of Spatial Bird Models

Forest Birds

Bird survey data collected in and adjacent to TFL 48 were used to develop volume-based habitat models for 10 indicator species. The data consisted of 14 breeding bird survey (BBS) routes that were visited one to five times between 2002 and 2006. The routes were placed along logging roads in and adjacent to Blocks 2, 4, and 5 of TFL 48. All but one route consisted of 50 stations (the exception having 25 stations), each separated by a distance of 800 m. Point counts were conducted once during the summer. All species seen and heard were recorded, along with information on weather conditions. Preston et al. (2007) provide additional details on the survey protocol. The survey stations were generally well distributed within the harvested and unharvested forest landscapes that lie within the boreal white and black spruce (BWBS), sub-boreal spruce (SBS), and Engelmann spruce-subalpine fir (ESSF) biogeoclimatic zones. No stations were located within the alpine tundra in the western half of the study area.

Several forest songbird species that are hypothesized to be sensitive to stand and landscape-level changes in forest conditions and that could be reliably modeled using map-based forest inventory data were selected. Specifically, selections were based on 1)

a prior knowledge of relationships to available habitat types in TFL 48, 2) a minimum frequency of detections of 5% at the surveyed stations to allow statistical modelling, and 3) an evaluation of the predictive accuracy of the models. This resulted in 10 candidate species representing a range of habitat conditions and having reliable models (Table 7). These species represent a variety of nesting guilds, a range of forest habitat conditions, and (with the exception of Townsend's Warbler and Western Tanager) have a high estimated percentage of their population that breeds within the boreal forest of Canada; thus they have many characteristics that make them suitable for evaluating forest management planning options.

Model Covariates

Vegetation resources inventory (VRI) data and volume maps generated from the SIMFOR simulation model were used to measure the composition of static and dynamic habitat variables around each bird count station (Table 8). All habitat attributes were measured within a 400 m radius (49.2 ha) around each sampling station. The size of the buffer was selected so as not to overlap between stations, which were 800 m apart. The proportion of water (lakes and rivers), non-vegetated (roads, urban, gas wells), and non-forested (wetlands, pasture, alpine meadows, seismic cutlines) habitat were measured using VRI data while the volume of deciduous trees, pine trees, and non-coniferous trees were measured from maps output from SIMFOR. Inventory data comprise several other attributes that are potentially useful for modelling wildlife habitat relationships such as tree species composition and estimated stand age[1]. One additional variable controlled for the influence of elevation in the models. All map layers were gridded to a 50 m resolution prior to measuring habitat characteristics and applying our habitat models to generate predicted probability of occurrence maps for each species for each projected time step.

[1] We initially developed habitat models using broad forest type and age class as covariates, but subsequently switched to volume-based covariates to better match the output of the simulation models. Our initial set of age-based models is described in a separate appendix.

Table 7. Description of selected avian indicators.

Code	Common name	Scientific name	Nesting	Habitat	SAS[1]	NAP[2]	Prev[3]
AMRE	American Redstart	*Setophaga ruticilla*	Tree, shrub	Deciduous forest, with abundant shrubs	OD	43%	0.178
LEFL	Least Flycatcher	*Empidonax minimus*	Tree	Mature deciduous forests and edges	OD	65%	0.108
OVEN	Ovenbird	*Seiurus aurocapillus*	Ground	Mature deciduous and mixedwood forests	OD	49%	0.078
RBGR	Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Tree, shrub	Deciduous forests, near edges with tall shrubs	OD	39%	0.057
REVI	Red-eyed Vireo	*Vireo alivaceus*	Shrub	Deciduous forests	OD	52%	0.062
TOWA	Townsend's Warbler	*Dendroica townsendi*	Tree	Mature coniferous forests	OC	14%	0.102
WAVI	Warbling Vireo	*Vireo gilvus*	Tree	Deciduous forest, riparian areas	OD, OM		0.493
WETA	Western Tanager	*Piranga ludoviciana*	Tree	Open coniferous and mixedwood forest	OM	13%	0.063
WTSP	White-throated Sparrow	*Zonotrichia albicollis*	Ground	Brushy undergrowth in coniferous forests	Recent, OD	83%	0.479
YEWA	Yellow Warbler	*Dendroica petechia*	Shrub, tree	Moist deciduous thickets	OD	47%	0.143

[1] Broad habitat preferences based on species accounting system (SAS) for TFL 48 (Bunnell and Vernier 2007). Recent = recently disturbed (<30 years), OD = old deciduous, OM = old mixedwood, OC = old coniferous.
[2] Estimated percentage of the North American population that breeds within the boreal forest of Canada and Alaska.
[3] Prevalence – frequency of stations that were occupied.

Table 8. Habitat covariates used to model selected forest bird indicators.

Variable Type	Variable	Description
Static	ELEV	Elevation in metres
	N_WATER	Presence of lake or river within 400 m buffer
	N_NONVEG	Percent nonvegetated habitat within 400 m buffer
	N_NONFOR	Percent nonforested habitat within 400 m buffer
Dynamic	N_VDECID	Volume of deciduous forest within 400 m buffer
	N_YCONIF	Volume of coniferous forest (excluding pine trees) within 400 m buffer
	N_VPINE	Volume of pine trees within 400 m buffer

Bird Models

Our modelling approach was based on relating species occurrences to habitat variables measured from observed and projected forest inventory data. Specifically, multiple logistic regression were used to estimate the probability of occurrence of each bird

species as a function of the habitat covariates (Vernier et al. 2002). For the purpose of modelling occurrence (station occupancy), a species was considered present at a station if it was detected in one or more years of sampling. For each species' model coefficients and their significance are reported. We evaluated the predictive performance of the avian indicators models using the area under the receiver operating characteristic (ROC) curve as a measure of how well the models were able to discriminate between sites where a species is present, from one where a species is absent (Harrell 2001, Vernier et al. 2008). A ROC value of ≥ 0.75 was considered to indicate a reliable model. A more stringent test using independent (out-of-sample) data was not possible for the volume-based models since covariate information was not available from the adjacent Fort St. John Forest District.

Model Projections

The ecological indicator models (logistic regression functions) were linked to the projected volume-based habitat grids to enable their projection over space and time. The functions were used to generate a probability of occurrence map for each bird species for each alternative management scenario at several time steps over a 100 year period. For each bird/scenario combination, we then summed all of the probabilities across all projected 0.25-ha pixels in the TFL 48 landbase to arrive at a landscape level suitability index standardized to year 0, the baseline year. Thus, the baseline year had an index value of 1. For each projected year thereafter, the index would increase or decrease relative to the baseline for a given species.

3 Results and Discussion

3.1 Stand-level analysis

3.1.1 Impacts of mountain pine beetle attack on stand dynamics

As illustrated in Figure 1, there are a number of key factors that influence the trajectory of stand development following MPB attack. The stand-level simulations conducted with FORECAST were designed to explore the effects of the following factors on post-attack stand dynamics:

- Attack severity (the level of pine mortality)
- Pine content (the proportion of pine in the stand prior to attack)
- Non-pine leading species (the leading non-pine species in the stand prior to attack)
- Age class (the age class of the stand prior to attack, as defined in Table 2).

Attack severity

The effect of varying the severity of MPB attack (see Tables A2-A3) on the long-term trends in the stand-level indicators is shown in Figures 5-7, for an example, Pl/Sw (50%-75% lodgepole pine with white spruce) stand type with two different pre-attack ages.

The impact of attack severity on long-term patterns in indicators was greatest for the MPB stand susceptibility index (SSI) followed by merchantable volume, snags, shrub cover, ecosystem carbon storage, and large live structure, respectively. The effect of increasing attack severity on some indicators also varied with the age of the stand at the time of attack. For example, the influence of increasing attack severity on shrub cover was strongest in the younger stand (age 40-80) in which shrubs were prevalent at the time of attack (Fig. 5). In contrast, the effect of increasing attack severity on the long-term maintenance of large diameter snags was more pronounced in the older stand (age > 80). In these stands the highest level of MPB attack led to extended periods of time with a low value in the snag index (Fig. 5). The effect of attack severity on the accumulation of merchantable volume was substantial at both ages with increasing levels of MPB-induced mortality showing long lasting negative impacts on merchantable volume (Fig. 7). Interestingly, lower levels of MPB attack led to the development of stands that were more vulnerable to future MPB attack as indicated by the Stand Susceptibility Index (Fig. 6). This pattern was related to that fact that the prevalence of spruce within the stand increased with increasing mortality of pine.

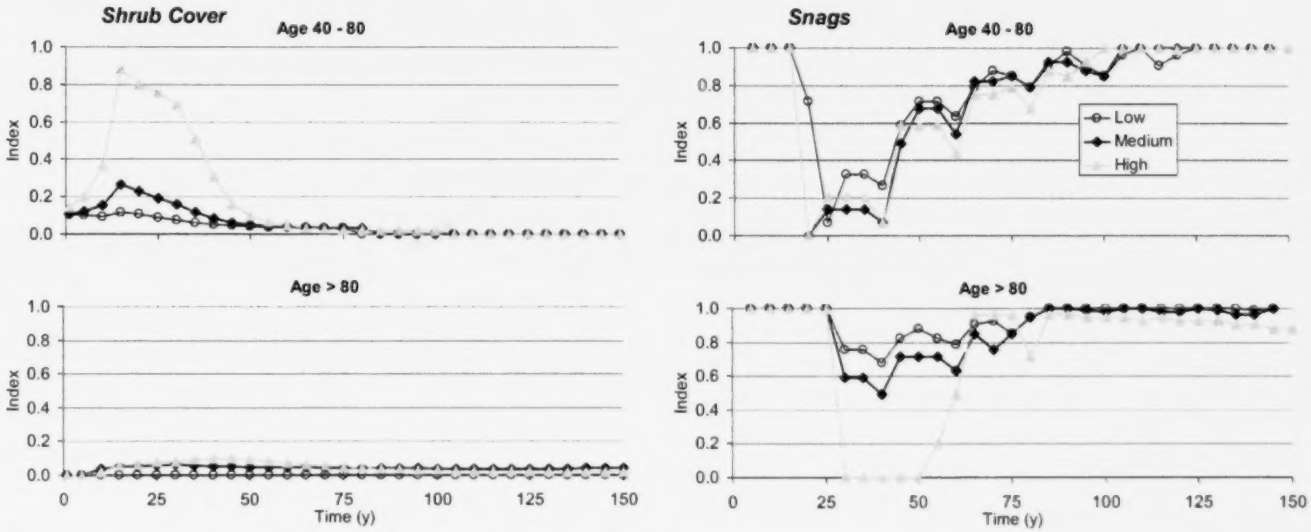

Figure 5. Simulation results showing the projected post-MPB-attack trend in Shrub Cover and Snag Index (0-1) for unsalvaged stands. The impact of level of MPB attack on index trajectories is shown for the pine-spruce (Pl/Sw) stand type (Pl content 50-75%) with two different ages at the time of attack. The time axis refers to time since initial attack.

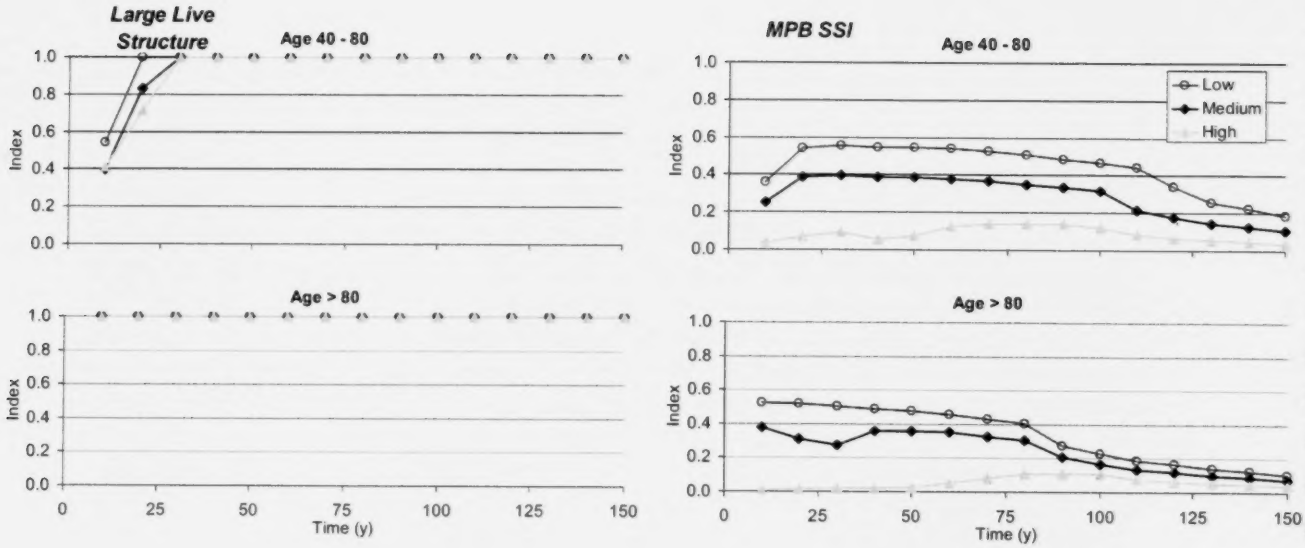

Figure 6. Simulation results showing the projected post-MPB-attack trend in Large Live Structure and MPB Susceptibility Index (0-1) for unsalvaged stands. The impact of level of MPB attack on index trajectories is shown for the pine-spruce (Pl/Sw) stand type (Pl content 50-75%) with two different ages at the time of attack. The time axis refers to time since initial attack.

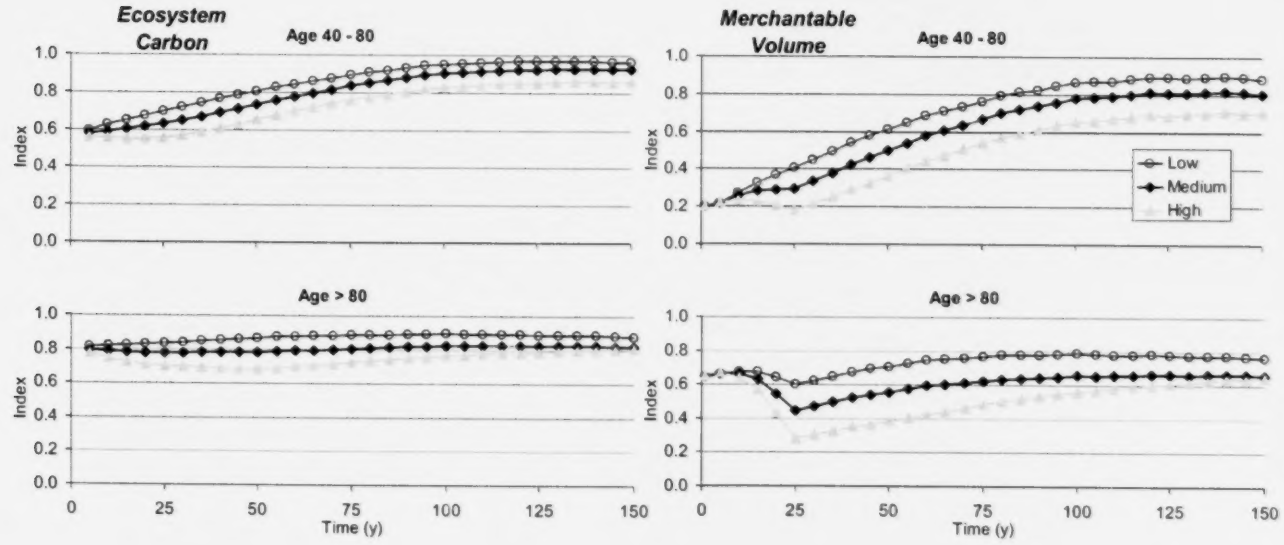

Figure 7. Simulation results showing the projected post-MPB-attack trend in Ecosystem Carbon and Merchantable Volume Index (0-1) for unsalvaged stands. The impact of level of MPB attack on index trajectories is shown for the pine-spruce (Pl/Sw) stand type (Pl content 50-75%) with two different ages at the time of attack. The time axis refers to time since initial attack.

Pine content

The influence of the pre-attack proportion of pine within a stand on long-term trends in indicators is illustrated for Pl/Sw and Pl/At (lodgepole pine with aspen) stand types in Figures 8-13 for the high level of MPB severity. As would be expected, the impact of MPB attack on patterns of post-attack stand development was greatest in stands with the highest initial pine contents.

Long-term trends in snag index were substantially influenced by initial pine content such that the higher was the initial pine content, the longer it took for the Snag index to recover following the loss of the snag cohort resulting from MPB mortality (Fig 9). The persistence of the initial MPB snag cohort as simulated by the model (15-25 years) was within the range of snag fall rates for similar forest types reported in the literature (Mitchell and Preisler 1998; Hawkes et al. 2003; Lewis and Hartley 2005). Differences in the mid-term recovery of the Snag index were related to higher recruitment rates from the greater populations of large live trees remaining in post-attack stands with lower initial pine contents.

The impact of initial pine content on Large Live Structure index was greater in the younger stands (age 40-80) for both the Pl/Sw and Pl/At stand types (Fig 10). The impact in the older stands (age >80) was small, as even the stands with higher initial pine contents retained enough large live trees to keep the index relatively high. The mid-term drop in Large Live Structure index in the Pl/At stand type is caused by the age-related aspen mortality built into the simulations in FORECAST. In the model, aspen is assumed to gradually die off as it approaches 150 years of age. The observed aspen-related decline is more pronounced in the stands with lower pine contents and higher aspen contents.

As would be expected, the post-attack accumulation of merchantable volume (as indicated by the Merchantable Volume index) was substantially reduced in stands with higher initial pine contents (Fig. 13). While the initial loss of volume was much greater for the older age class (age >80), the trend of reduced volume accumulation was evident in the younger age class (age 40-80) as well. This pattern was related both to the mortality of existing pine and the delay in natural regeneration which established at lower densities (see Table A3) relative to the fire-originated stands present prior to the MPB attack. As described above, the mid-term declines in merchantable volume in the Pl/At stands were related to the age-related aspen mortality.

The trend in the Ecosystem Carbon Storage index was similar to that observed for merchantable volume (Fig 12). The principal difference among the stands with different initial pine components was caused by decreased carbon storage in tree biomass in stands with higher initial pine contents and associated MPB-related mortality. The relatively large and persistent impact (with respect to indices of volume and carbon storage) of MPB on stands with higher initial pine contents highlights the potential benefit of salvaging and re-establishing such stands.

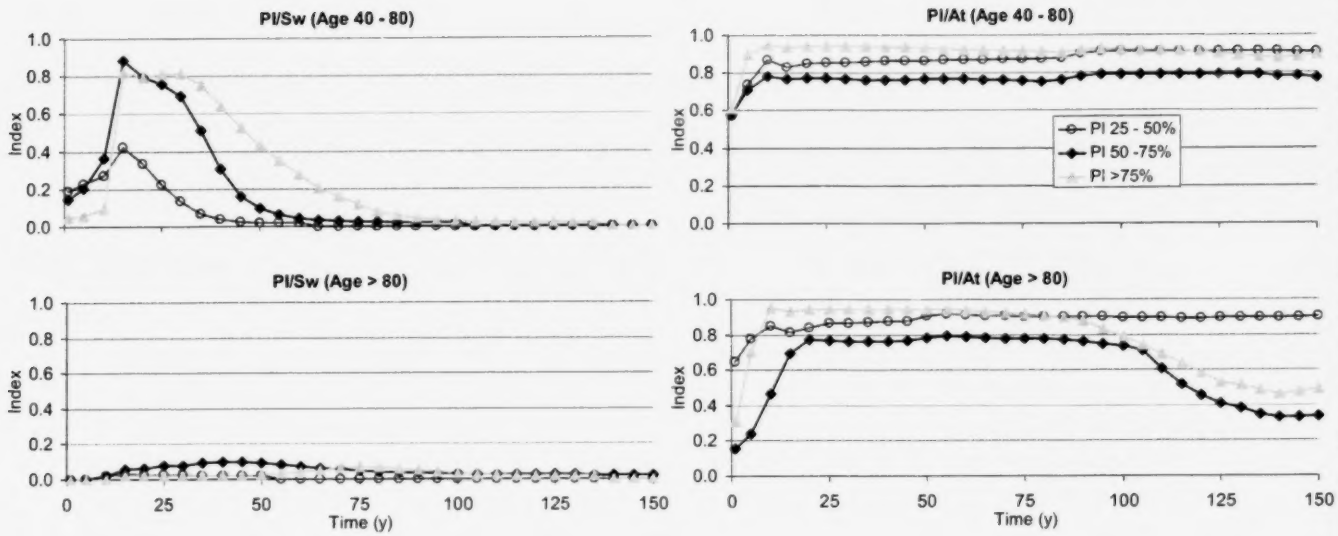

Figure 8. Simulation results showing the projected post-MPB-attack trend in Shrub Cover Index (0-1) for unsalvaged stands. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in percent pine and age at the time of attack. The time axis refers to time since initial attack.

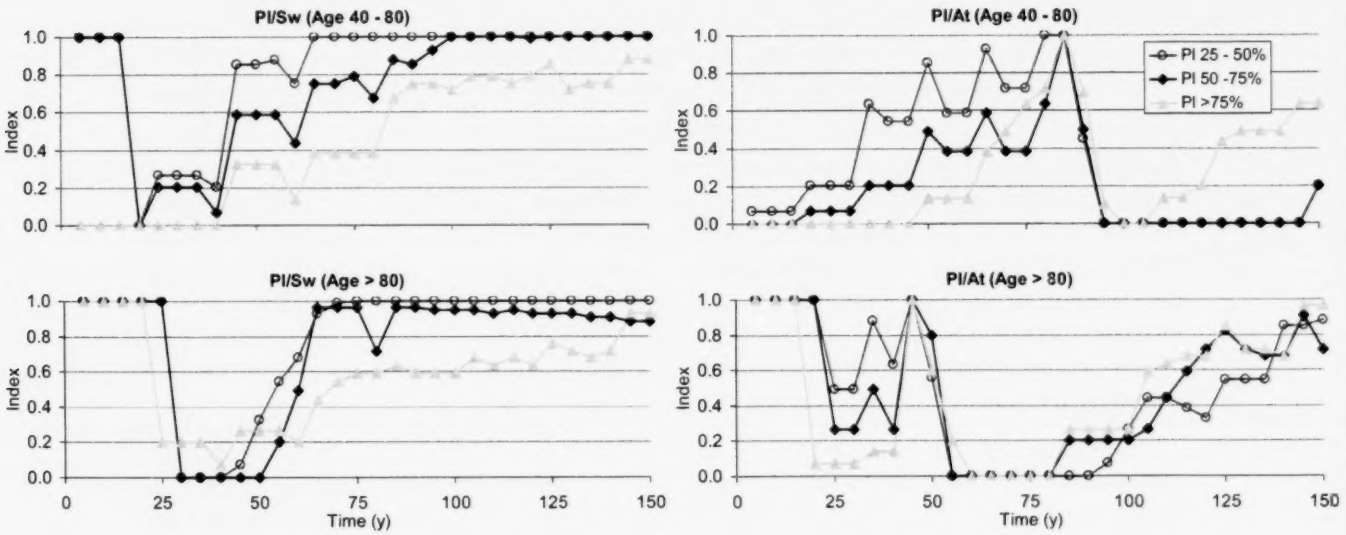

Figure 9. Simulation results showing the projected post-MPB-attack trend in Snag Index (0-1) for unsalvaged stands. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in percent pine and age at the time of attack. The time axis refers to time since initial attack.

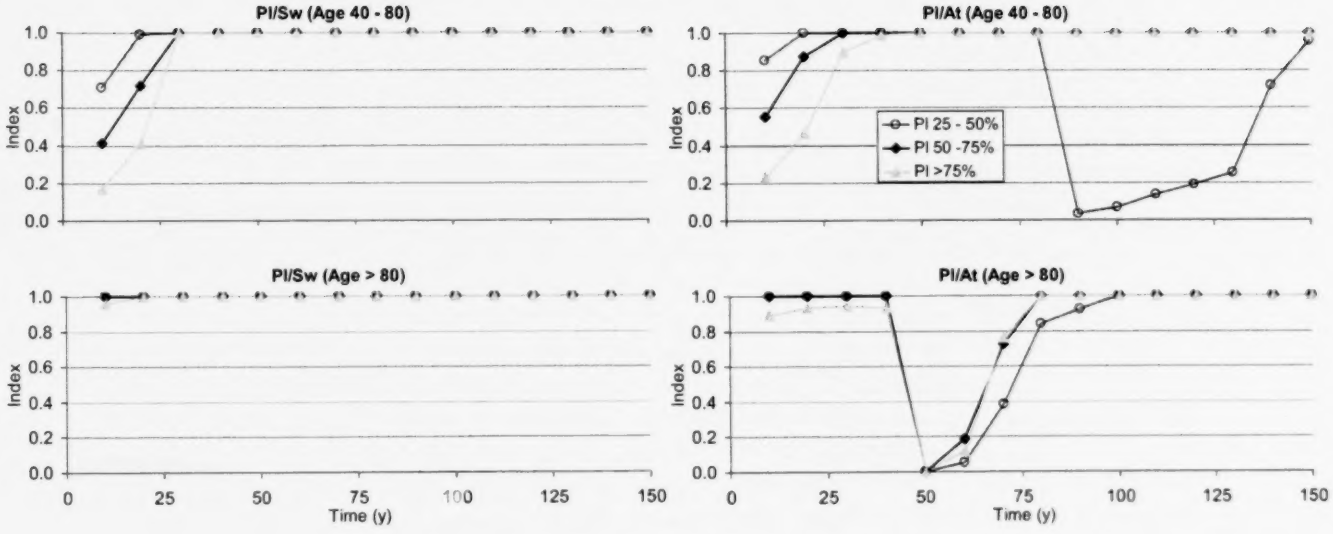

Figure 10. Simulation results showing the projected post-MPB-attack trend in Large Live Structure Index (0-1) for unsalvaged stands. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in percent pine and age at the time of attack. The time axis refers to time since initial attack.

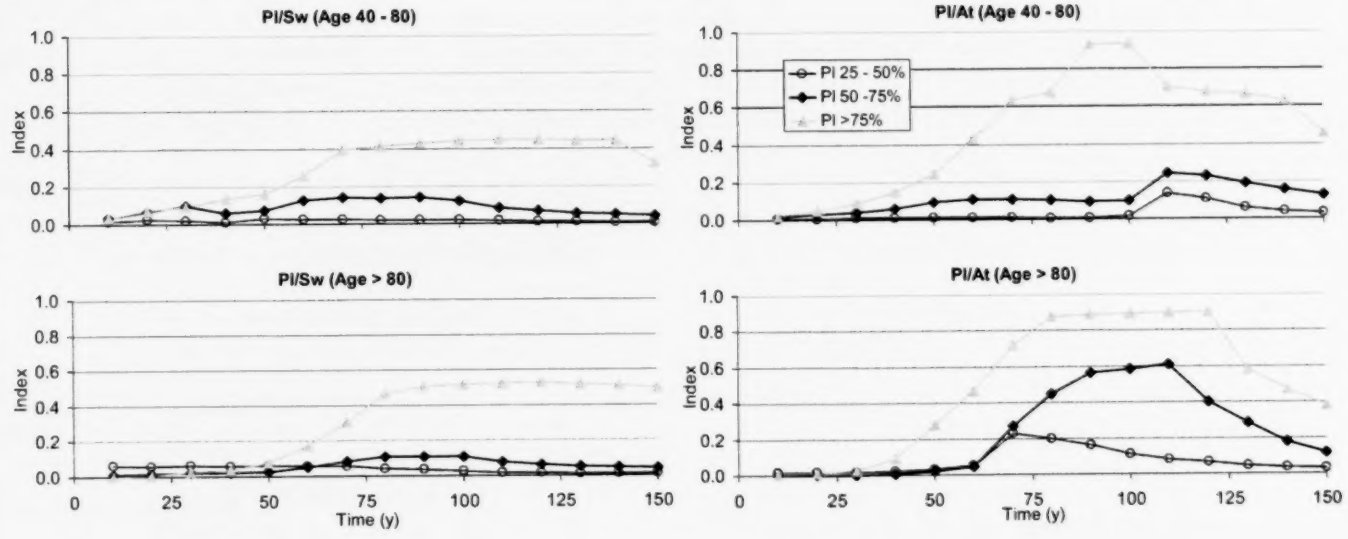

Figure 11. Simulation results showing the projected post-MPB-attack trend in MPB SSI Index (0-1) for unsalvaged stands. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in percent pine and age at the time of attack. The time axis refers to time since initial attack.

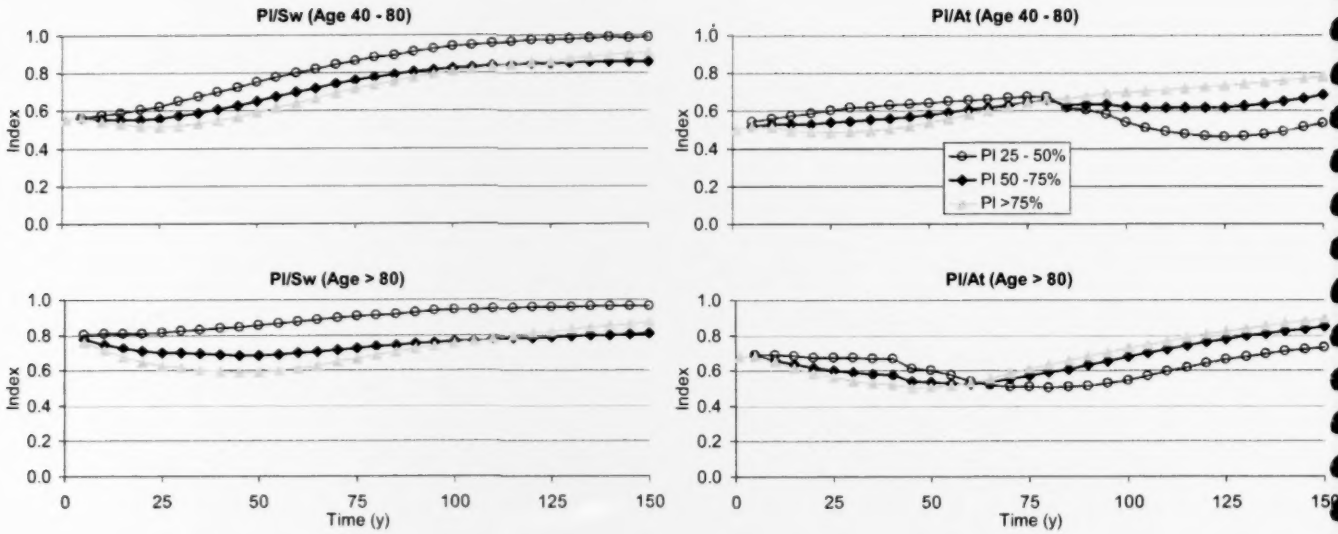

Figure 12. Simulation results showing the projected post-MPB-attack trend in Ecosystem Carbon Index (0-1) for unsalvaged stands. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in percent pine and age at the time of attack. The time axis refers to time since initial attack.

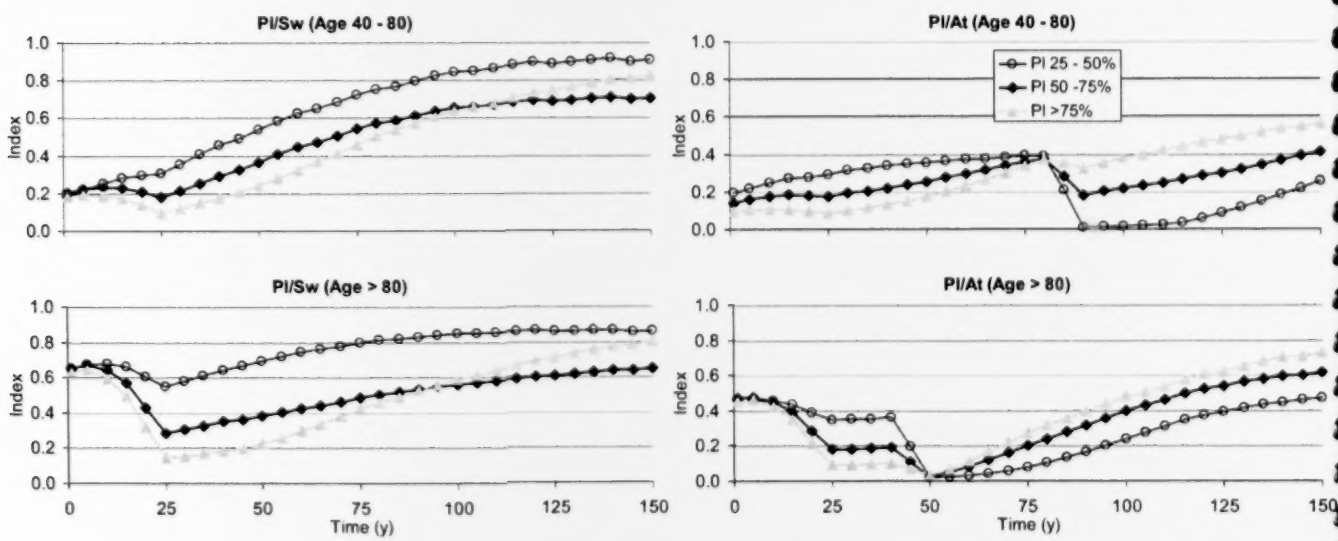

Figure 13. Simulation results showing the projected post-MPB-attack trend in Merchantable Volume Index (0-1) for unsalvaged stands. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in percent pine and age at the time of attack. The time axis refers to time since initial attack.

3.1.2 Analysis of alternative salvage options

The relative impact of the three alternative salvage objectives (see Section 2.2) on the long-term trajectories of indices of the different stand-level indicators is shown for representative Pl/Sw and Pl/At stand types (each with pine initial pine contents of 50-75%) in Figures 14-16. In all cases the salvage alternatives are compared against a no-salvage option to provide a frame of reference.

The biodiversity salvage treatment showed substantial benefits for the indices of large live structure and snags in both Pl/Sw and Pl/At stand types relative to the other treatments (Fig 14). In the case of the Large Live Structure index, the benefits were greatest during the first 3-4 decades following harvest. The benefits to the Snag index took a bit longer to develop, but persisted for 7 to 8 decades following salvage. Since the retention of live structure in the biodiversity salvage scenarios was assumed to be distributed throughout the stand, it was assumed that all snags were removed at the time of harvest (accounting for the lack of snags early on). If the retention had been implemented as patches, some of the snags within the stand would have been preserved and the resulting Snag index would have been higher during the first few decades following salvage. Interestingly, the biodiversity treatment appeared to reduce the future susceptibility of the stand to MPB attack (as indicated by the MPB SSI index) to levels similar to those resulting from the risk reduction treatment (Fig. 15).

As expected, the productivity treatment showed the highest index values for merchantable volume, particularly around the probable rotation-length period of 60 to 90 years (Fig. 16). While the biodiversity treatment stands showed similar levels of early merchantable volume, these values are elevated by the retention of live structure in this treatment (approximately 10% of the stand volume is left behind at harvest, see Table A5). Coates et al. (2006) suggest that protection of advanced regeneration of spruce and other species during MPB salvage could provide a similar boost in short-term volume production. In the present analysis, it should be noted that the actual volume harvested during salvage in the biodiversity treatment would have been 10% less than that for the same stand harvested using one of the other salvage methods because of the retention requirements. An important trade-off to be considered when managing for higher short-term productivity by planting a higher percentage of pine and fertilizing is that the resulting stand will be more vulnerable to future MPB attack as indicated in Figure 15. The vulnerability of the stands salvaged using the productivity treatment tends to increase dramatically as the pine matures (from age 50 to 80), after which it levels off.

The differences among the different salvage treatments on ecosystem carbon storage were relatively small (Fig. 15). However, there was a substantial difference in the trend in Ecosystem Carbon Storage index between the salvaged and unsalvaged stands. In general, the unsalvaged stands had higher levels of storage for the first 3-4 decades following salvage. This trend was reversed as the stands aged and the salvaged, more densely stocked stands accumulated greater quantities of tree biomass. Further, if storage in harvested wood products were included, total storage during the first few decades in the salvaged stands would be more similar to that in the unsalvaged stands.

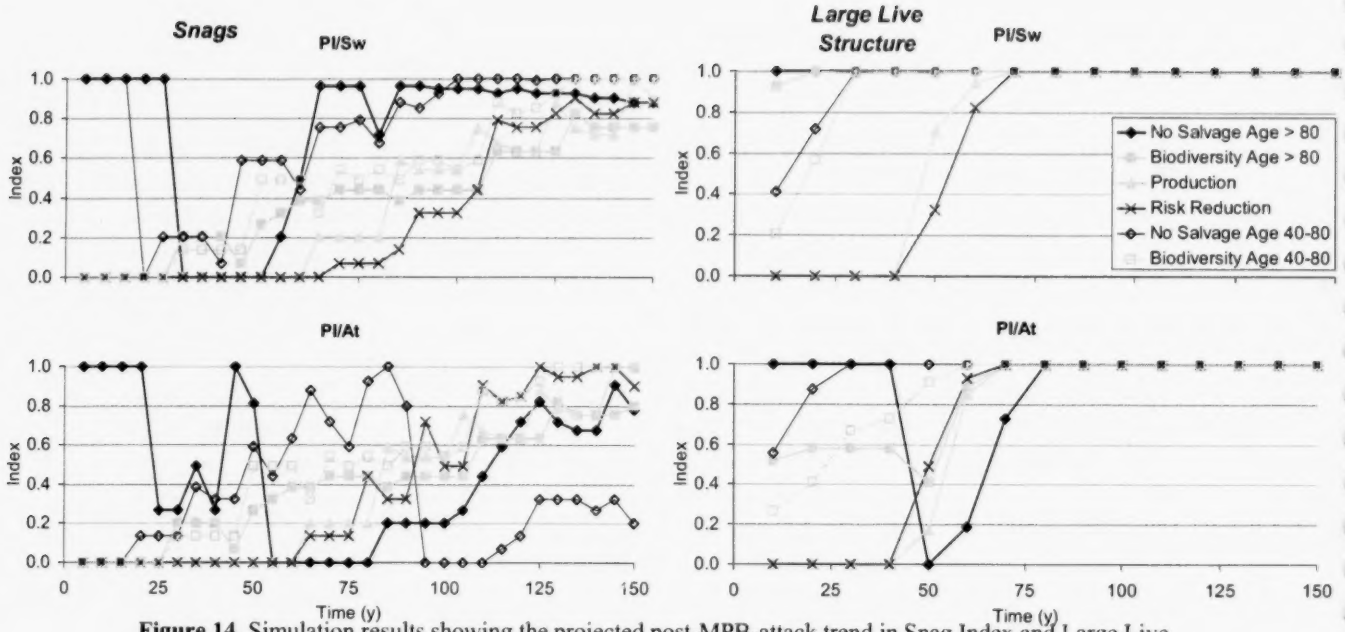

Figure 14. Simulation results showing the projected post-MPB-attack trend in Snag Index and Large Live Structure Index (0-1) for stands salvaged with different objectives. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in age at the time of attack. The time axis refers to time since initial attack for unsalvaged stands and time since salvage for salvaged stands.

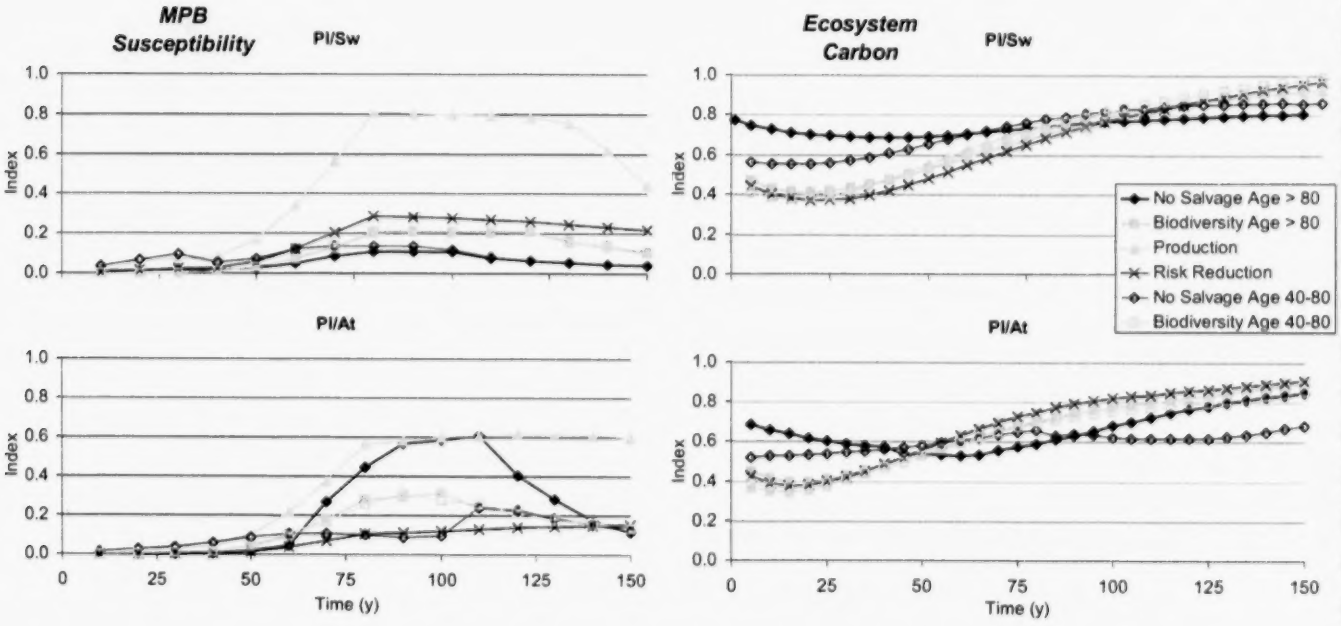

Figure 15. Simulation results showing the projected post-MPB-attack trend in MPB Susceptibility Index and Ecosystem Carbon Index (0-1) for stands salvaged with different objectives. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in age at the time of attack. The time axis refers to time since initial attack for unsalvaged stands and time since salvage for salvaged stands.

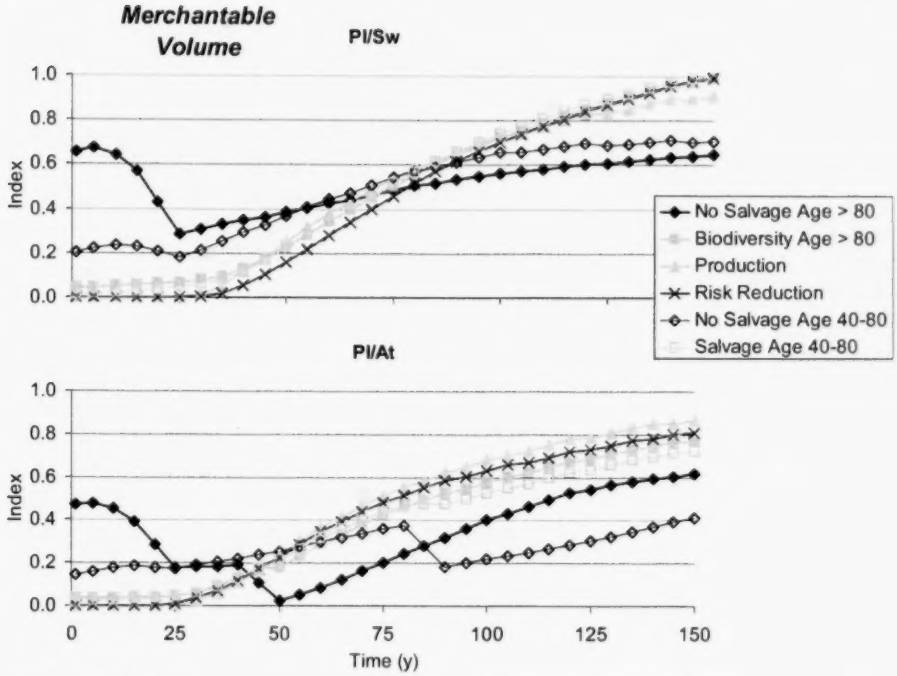

Figure 16. Simulation results showing the projected post-MPB-attack trend in Merchantable Volume Index (0-1) for stands salvaged with different objectives. Differences in index trajectories are shown for both pine-spruce (Pl/Sw) and pine-aspen (Pl/At) stand types that vary in age at the time of attack. The time axis refers to time since initial attack for unsalvaged stands and time since salvage for salvaged stands.

3.2 Landscape-Scale analysis

3.2.1 The ATLAS Harvest Schedules

Results are first reported for Phase 1 of the landscape-scale analysis that includes the MPB level of attack (High and Low), stand management objectives (BIO, PROD, RISK) and salvage intensity (100% and Pine 3). These include the annual harvest (m3/year), harvest volume by stand type (m3/year) and growing stock (m3) for both the salvage period (years 1-15) and the post-salvage period (years 25-105). While all scenarios were projected for 245 years to ensure stable harvest and growing stock levels, we report the long-term as only covering years 25-105. The reason is that harvest and growing stock levels did not change between years 105 and 245, an initially surprising result that is discussed further in this section of the report. We then report our results for the Phase 2 zone analysis where scenarios based on the high MPB attack, PROD stand management objective and Pine 3 salvage intensity were run under the zone strategy (Hardwood and Diverse) and the zone intensity (10% and 20% of the THLB). In addition to harvest and growing stock, we also report average profitability and the length of active road for each scenario.

Phase 1: Attack level, stand management objectives and salvage intensity

Average Annual Harvest

Figure 17 summarizes the average annual harvest for the Phase 1 landscape scale analysis during both the salvage period and post-salvage period. For the salvage period, the highest harvests are in Hi_Prod_100 and Hi_Risk_100, followed by Hi_Prod_Pine3 and Hi_Risk_Pine3. The next highest harvest occurs in four scenarios Low_Prod_100, Low_Risk_100, Low_Prod_Pine3 and Low_Risk_Pine3. The lower harvests during the salvage period were in the Bio scenarios, with HI_Bio_100 and Hi_Bio_Pine 3 the highest and Low_Bio_100 and Low_Bio_Pine 3 the lowest. The high attack level requires more salvage harvest than the low attack level, and likewise, the 100% salvage intensity requires more salvage harvest than the corresponding Pine3 salvage intensity. During the post-salvage period, the harvest levels for all the Production and Risk Reduction scenarios were similar, with only slightly higher values observed in the Productivity scenarios. This modest difference was caused by the relatively lower volume in the spruce-dominated stands associated with the Risk Reduction scenario relative to the more productive pine-dominated stands associated with the Productivity scenario (see Fig. 16) The Biodiversity scenarios have the lowest post-salvage harvest levels because of the high degree of stand retention constraints that were applied.

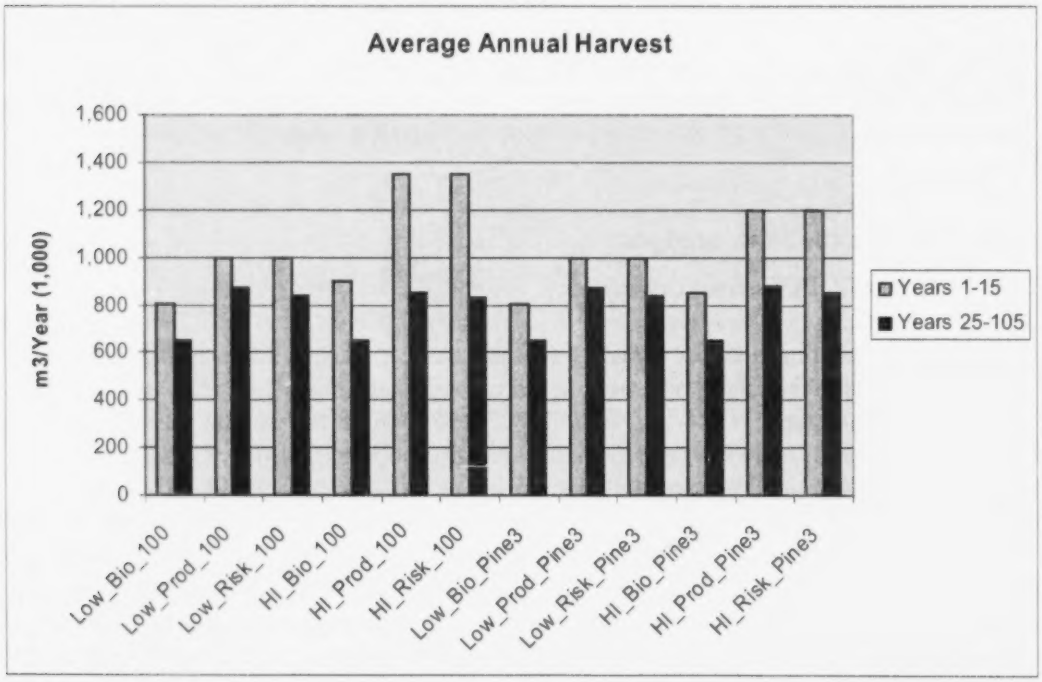

Figure 17. Summary of the average annual harvest (m3/year) for the Phase 1 landscape scale analysis scenarios during the salvage period (years 1-15) and the post salvage period (years 25-105). From left to right, the first six scenarios represent 100% salvage intensity (beginning with Low MPB attack and progressing to High MPB attack), while the last six scenarios represent the corresponding results for the Pine 3 salvage intensity.

Within an attack level and salvage intensity, harvests for the Productivity and Risk Reduction stand management objectives give similar results. With the exception of the Biodiversity scenarios, the general observation is that higher salvage harvests tend to result in lower post-salvage harvests. Typically, we expect that high salvage harvests will result in low harvests in the mid-term before the forest fully recovers in the long term. We did not observe this mid-term drop in our scenarios for two reasons. First, TFL 48 currently has a considerable buffer of available growing stock, including non-Pl stands, and second, the salvage operations were completed in only 15 years, at relatively modest salvage rates. At the end of the salvage period, non-Pl stands were immediately available for mid-term harvests while the Pl stands recovered to satisfy the long-term harvests (Figure 18). It was only when the salvage rate was accelerated (approximately 2 million m3/year for <15 years) that we observed the typical mid-term fall down.

Figure 18 shows the annual harvest by general stand type for the Hi_Prod_Pine3 scenario. This pattern of exclusively harvesting attacked stands during the salvage period and then switching to unsusceptible and regenerated stands is typical of all scenarios. The majority of these 'unsusceptible' stand types are located in the wet mountain forest area which is dominated by Engelmann spruce and subalpine fir. The small portion of attacked stands harvested in the post-salvage period is caused by stands that did not reach the minimum harvest volume of 200 m3/ha until that time.

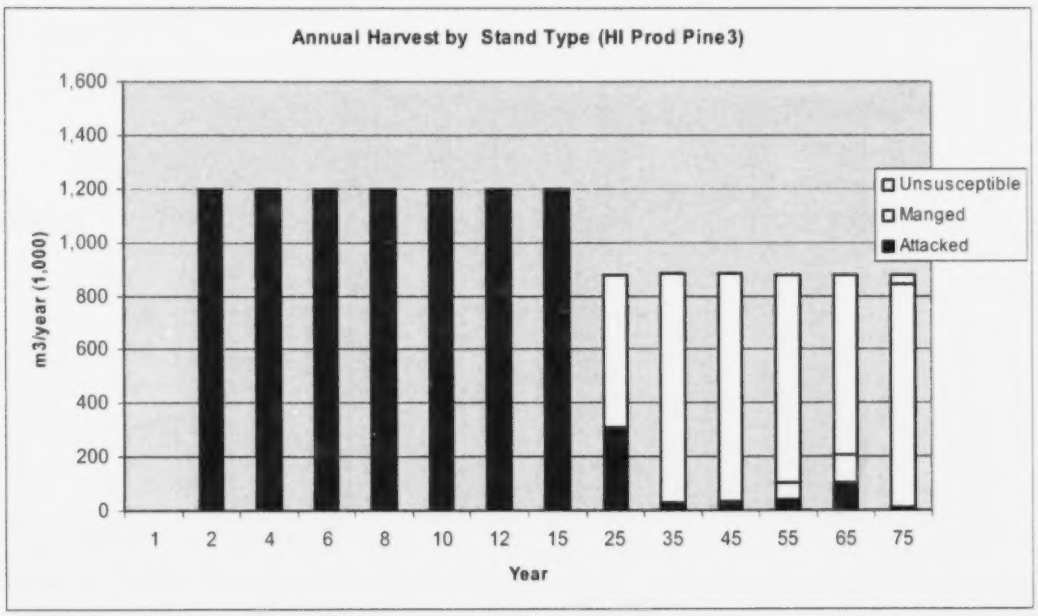

Figure 18. Annual harvest by general stand type for the Hl_Prod_Pine3 scenario. Harvest during the salvage period is exclusively from attacked stands and then switches to unsusceptible and managed (regenerated) stands. Some attacked stands are harvested in the post salvage period because they did not reach the minimum harvest volume (200 m3/ha) until that time.

Phase 2: Zone Type and Zone Intensity Analysis

Average Annual Harvest

Figure 19 summarizes the average annual harvest during the salvage and post-salvage periods for the key Phase 1 and Phase 2 scenarios. These results indicate that salvage harvest levels were most sensitive to the zoning strategy, followed by zoning intensity. The Hardwood zone strategy had higher harvest levels during the salvage period because the reserved hardwood-containing stand types in this scenario have relatively smaller volumes and lower harvest priorities relative to the stand types set aside in Diverse zone strategy, which include many that are important sources of timber during the salvage period. In contrast, harvest levels during the post-salvage period were higher for the Diverse Zoning strategy than for the Hardwood Zoning strategy, given a common zoning intensity. This was primarily a consequence of the higher salvage levels in the Hardwood strategy leading to a longer recovery period for the growing stock.

A comparison of the Phase 2 zoning strategies to two key Phase 1 scenarios showed that salvage levels were similar in Hi-Prod-Pine3 and Hardwood scenarios (Fig. 19). Likewise, the Hi-Bio-Pine3 and Diverse Zoning scenarios had similar salvage levels. Post-salvage harvest levels were highest in Hi-Prod-Pine3 scenario followed by the 10% zoning strategies. Overall, the most significant differences among scenarios were observed during the salvage period (years 1-15).

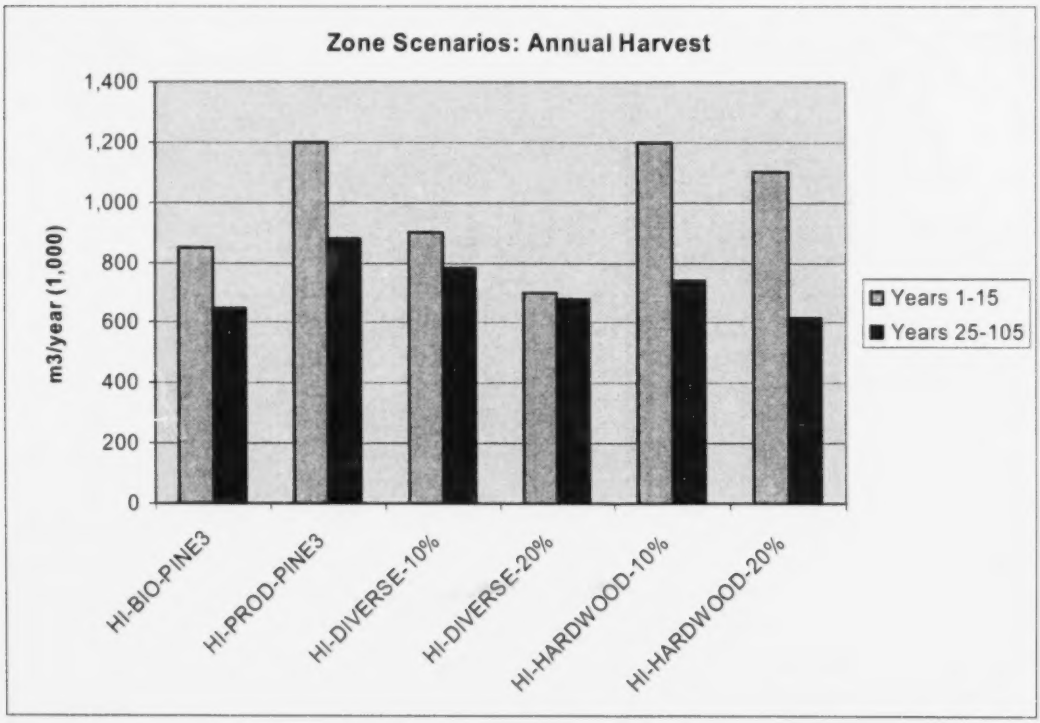

Figure 19. Average annual harvest for the key Phase 1 and Phase 2 zoning scenarios during the salvage and post-salvage periods.

Growing Stock

Figure 20 shows the trends for non-reserved growing stock for the Hi_Prod_Pine3 and Hi_Prod_Hardwood_10% scenarios that are typical of all scenarios. Growing stock sharply declined during the salvage period when only attacked stands were available for harvest. It then dramatically increases as unsusceptible and lower priority Pl stands are made available for harvest at or near the end of the salvage period, and then stabilizes at about 60 years. The very low growing stock at the end of the salvage period was expected because the annual harvest during the salvage period was maximized in all scenarios. The growing stock in Hi-Hardwood-10% scenario was lower than that in the Hi-Prod-Pine3 scenario (Fig. 20) because area excluded from salvage harvest in the zoning scenarios remained unavailable throughout the whole simulation period.

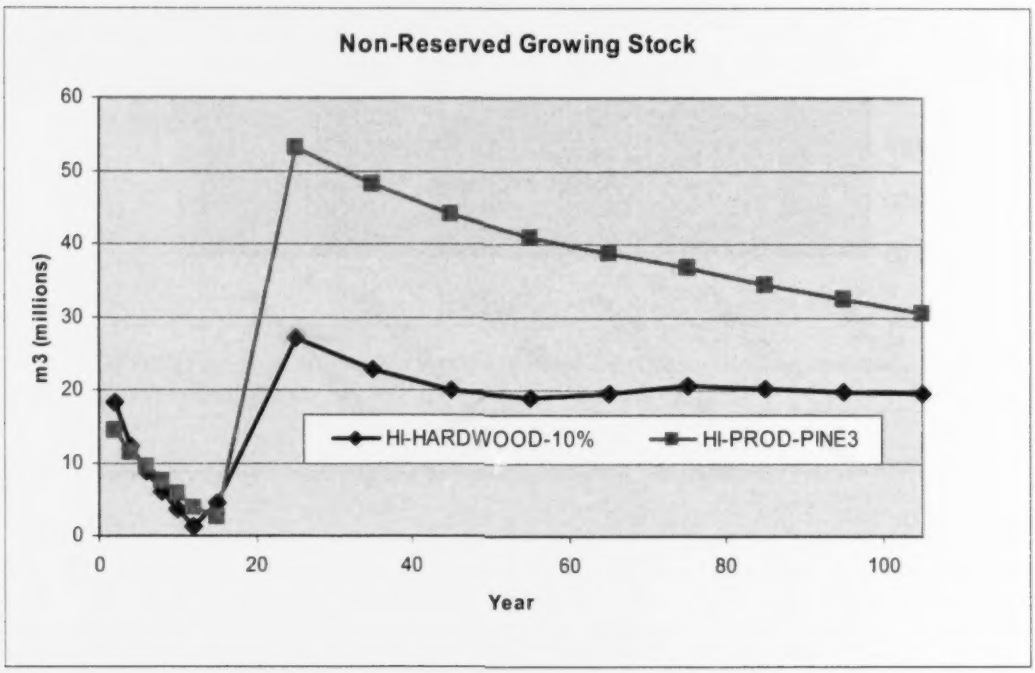

Figure 20. Example of non-reserved growing stock for the HI_Prod_Pine 3 and HI_Prod_Hardwood_10% scenarios.

Profitability

Figure 21 shows the average profitability for the key Phase 1 and Phase 2 scenarios during the salvage and post-salvage periods. During the salvage period, profitability for all scenarios was similar. Profitability was consistently higher during the salvage period relative to the post-salvage period. This resulted from the fact that harvest priority in ATLAS was set to prioritize low-cost Pl, high-value stands during the salvage period. The zoning scenarios had slightly higher post-salvage profitability relative to the Phase 1 scenarios because harvests were more spatially concentrated in these scenarios, providing economies of scale. This interpretation is supported by the relatively smaller amount of

active road network required for the zoning scenarios (see below). The Hardwood zone scenarios show modestly higher post-salvage profitability than the Diverse zone scenarios because there were more low cost Pl stands available for harvest in the long-term with the Hardwood Zoning strategy.

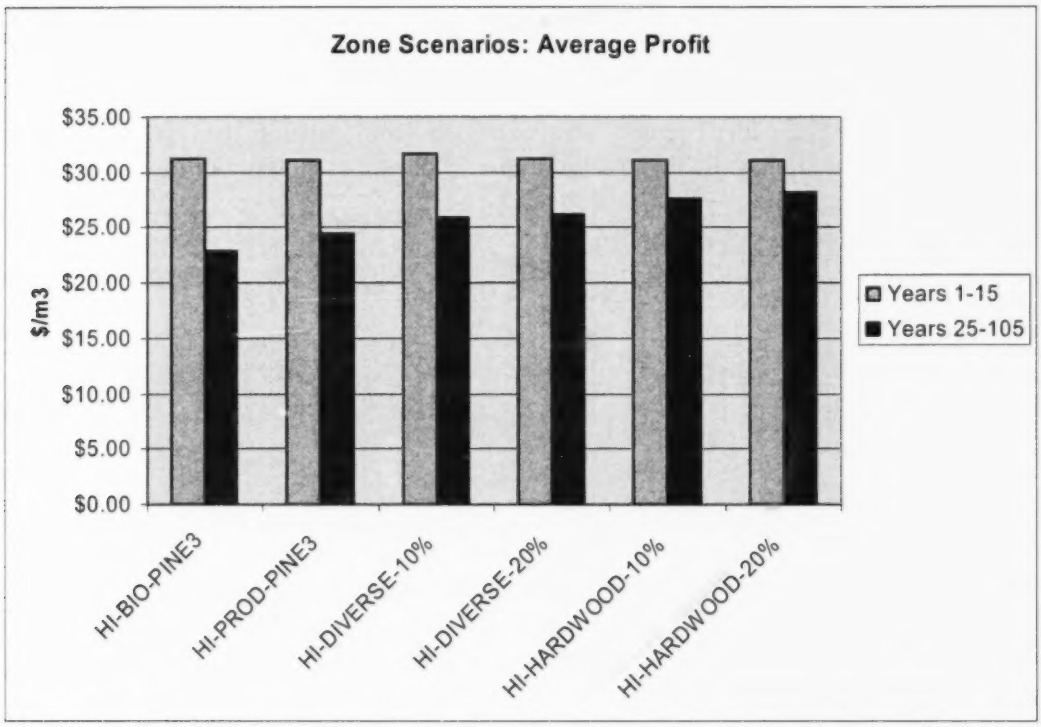

Figure 21. Average profitability for the key Phase 1 and Phase 2 scenarios during the salvage and post salvage periods.

Average Length of Active Road

The average length of active road for the key Phase 1 and Phase 2 scenarios during the salvage and post-salvage periods is shown in Figure 22. For all scenarios, the average amount of active road was lower during the salvage period than in the post-salvage period because the harvest was restricted to the more accessible Pl stands during salvage operations. The zoning scenarios have slightly less active road during the salvage period than the Phase 1 scenarios because their harvests are more spatially concentrated. There is little difference in the amount of active road during the post-salvage period for all scenarios. We did not explicitly model different road networks to minimize access in the zoning scenarios, hence the reduction in amount of active road relative to the Phase 1 scenarios was modest at best.

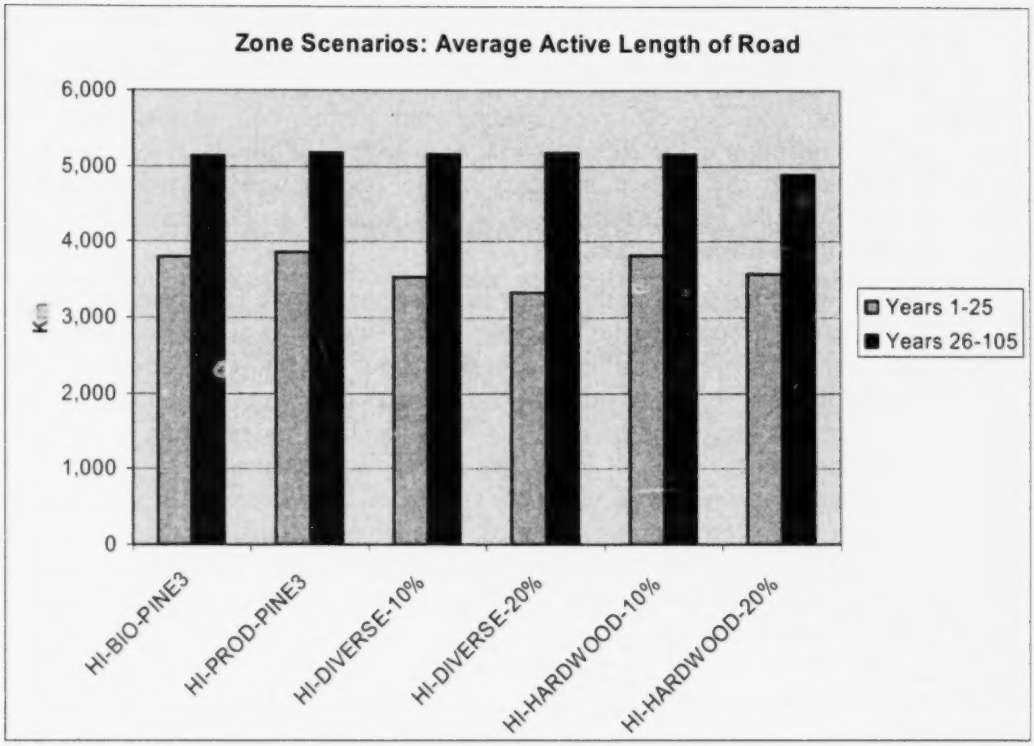

Figure 22. Average length of active roads for the key Phase 1 and Phase 2 zoning scenarios during the salvage and post-salvage periods.

3.2.2 Landscape summaries of biodiversity and risk indicators

Snag Index

The Pine Leading Conifer stratum showed the greatest differences in mean landscape Snag index among scenarios followed by the Deciduous/Mixedwood and the High Elevation Spruce Balsam in which there was almost no difference among scenarios (Fig. 23). The reason for the small response to scenarios in this stratum is the fact that pine represents only a small component of these forest types and thus the different salvage and zoning approaches have little impact. The response to the management scenarios in the Deciduous/Mixedwood stand type was most pronounced in the zoning scenarios, with the Hardwood Zoning scenarios showing the highest levels of snag retention because of their focus on retaining mature deciduous-leading forests. Not surprisingly, the Hardwood Zoning scenarios also had the highest level of deciduous snag retention (data not shown).

As expected, the pine leading conifer stratum showed an initial sharp increase in the landscape-level Snag index in all scenarios, reflecting high tree mortality following the simulated MPB outbreak (Fig. 23). The Hi-Prod-Pine3 scenario, which had no retention provisions, performed the poorest for all three strata. In contrast, the Hi-Bio-Pine3 scenario maintained high initial snag levels for an extended time period in the Pine leading Conifer stand type, reflecting the retention of within-stand reserves in this

scenario (see Section 3.1.2). However, there was a mid-term decline in snag retention in this scenario, presumably due to the gradual loss of MPB-killed snags and slow recruitment of new snags in reserve areas. The Diverse Zoning scenarios (10% and 20% landscape-level retention) produced the most balanced snag retention both across the planning horizon and between pine leading and mixedwood stands, with higher landscape-level retention in the 20% scenario, as expected. While the Hardwood Zoning scenarios resulted in the highest retention in the Deciduous/Mixedwood stratum, it performed poorly in the Pine Leading Conifer stand types (Fig. 23) because all retention is concentrated in the former stratum.

Snag retention was considered in this study because snags have long been known to be important for cavity nesting species (Thomas 1979; Bunnell et al. 1999; Bunnell et al. 2002), and there have been significant concerns about the mid-term effects on cavity nesting species in areas with large-scale MPB outbreaks (Martin et al. 2006). The results of our study bear out these concerns. In the Pine Leading Confer stands, which form a significant portion of the TFL-48 landscape (21%), we observed a 35-year gap with limited landscape-level snag levels under our simulation conditions for all scenarios, with the exception of the Diverse Zoning scenarios. The Diverse Zoning strategy was the best option for providing balanced results through time and across stand types. The 20% Diverse Zoning option provides mean landscape Snag index levels similar to pre-attack levels (year 0) through the mid-term recruitment gap, but substantially higher values in the long run. These results suggest that a hybrid approach, with higher mid-term retention levels and declining long term retention in pine conifer stands, might be considered.

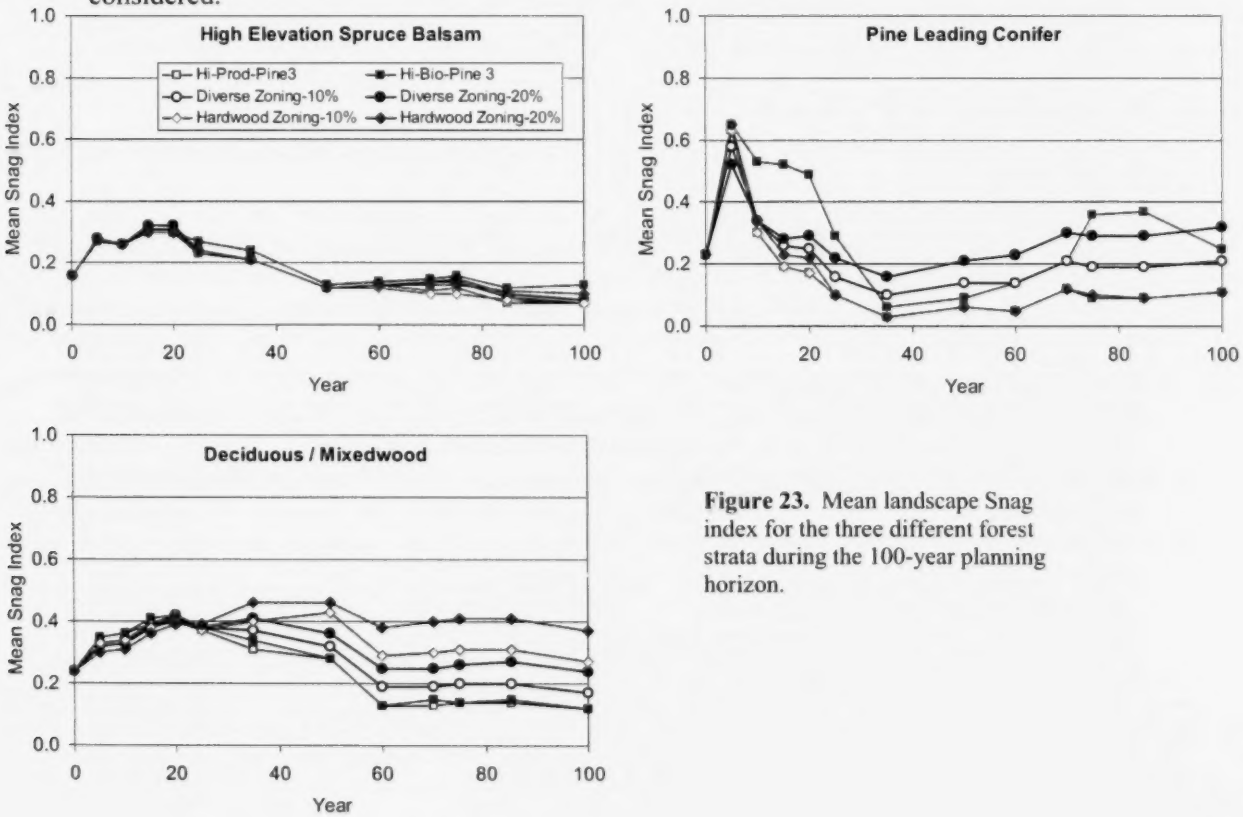

Figure 23. Mean landscape Snag index for the three different forest strata during the 100-year planning horizon.

Large Live Structure Index

Like the Snag index, the mean landscape Large Live Structure index responded positively to scenarios with increased levels of retention (Fig. 24), particularly for the Pine Leading Conifer and Deciduous/Mixedwood strata. Interestingly, the index showed a steady decline in all scenarios in the High Elevation Spruce Balsam stratum. This was caused by the harvest scheduling model having to rely heavily on this stratum during the interim period following the initial salvage (see Section 2.3.1). Further, this slow-growing, high elevation forest type takes a relatively longer time to recover mature stand attributes.

As would be expected, Hi-Bio-Pine3 scenario performed well in all strata with the exception of the Deciduous/Mixed stand type. The reason for its poorer performance in this stratum was related to the fact that the retained mature deciduous stems in this scenario have a relatively short life span and tended to die off during the post-salvage interim period (see Section 3.1). This is in contrast to retained mature spruce stems which generally survived throughout the planning horizon. As was the case for mean Snag index, the Diverse Zoning scenarios tended to provide the most balanced results when considering all strata. The 20% retention level performed better than 10% retention in that the mean landscape Large Live Structure index was maintained at levels similar to initial conditions in all strata, with the exception of High Elevation Spruce Balsam. The degree to which this slow-growing forest type can absorb the interim harvest is not clear. Results shown here indicate that there was a substantial loss of mature forest conditions (as indicated by the Snag and Large Live Structure indices), which in turn may have a negative impact on species dependent on such conditions.

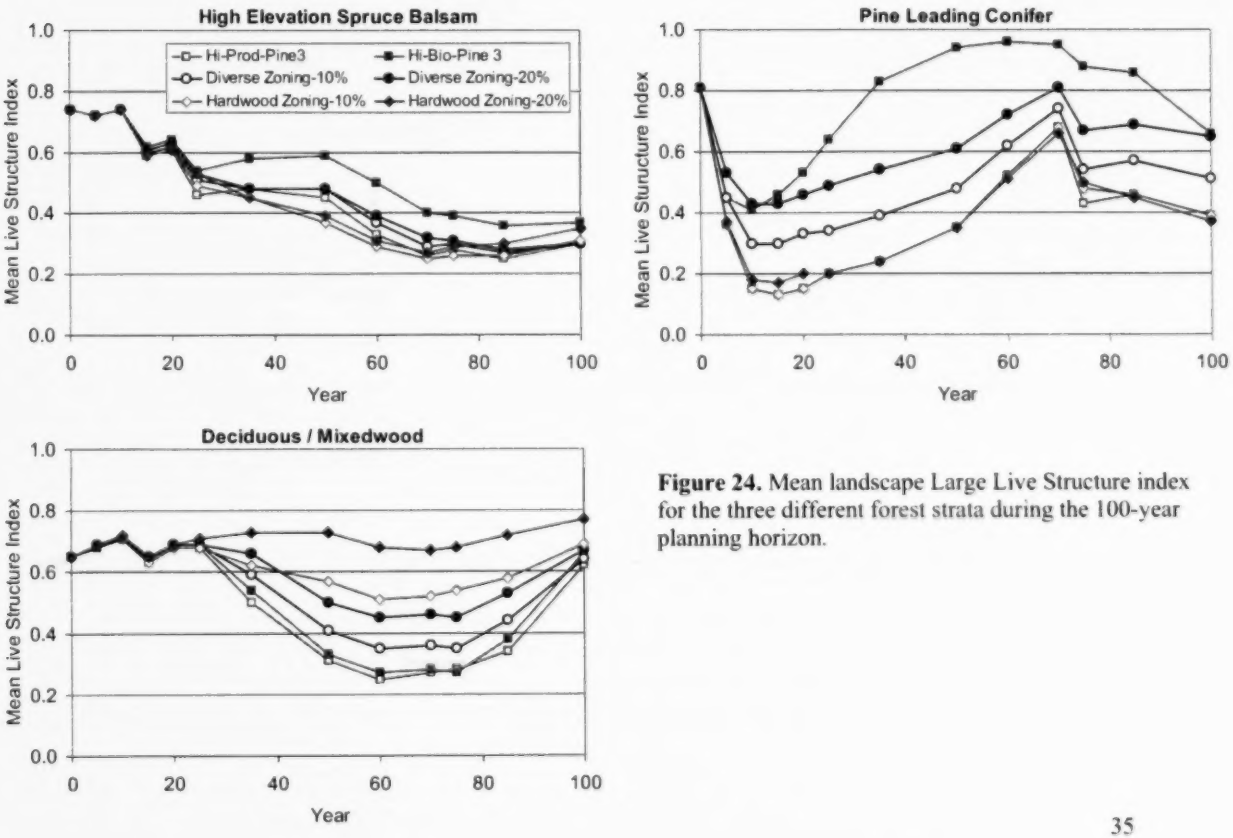

Figure 24. Mean landscape Large Live Structure index for the three different forest strata during the 100-year planning horizon.

Mountain Pine Beetle Susceptibility Index

The mean landscape MPB Susceptibility index is only shown for the Pine Leading Conifer stratum (Fig. 25) as susceptibility levels in the other forest strata were low throughout the planning horizon. The relatively high susceptibility level observed prior to MPB-attack was not reached again in any of the scenarios throughout the planning horizon. This is primarily because of the time required for regenerated pine to recover to mature conditions with high index values (see Section 3.1) and because as regenerated stands began to show substantial increases in the MPB Susceptibility index they were being harvested (see Fig. 18). This is evident in the drop in the mean landscape MPB Susceptibility that occurs in all scenarios around year 70.

The Diverse Zoning scenarios showed the highest susceptibility levels throughout the planning horizon as mature pine-containing stands were included in the reserves. As was found in the stand-level analysis, the Hi-Bio-Pine3 scenario showed the lowest susceptibility to future MPB attacks. From these results, it appears that MPB susceptibility can be mitigated by either retaining mature non-pine trees during salvage or by harvesting pine-containing stands before susceptibility levels reach their peak. The latter option would likely have negative impacts on species requiring the maintenance of mature forest conditions.

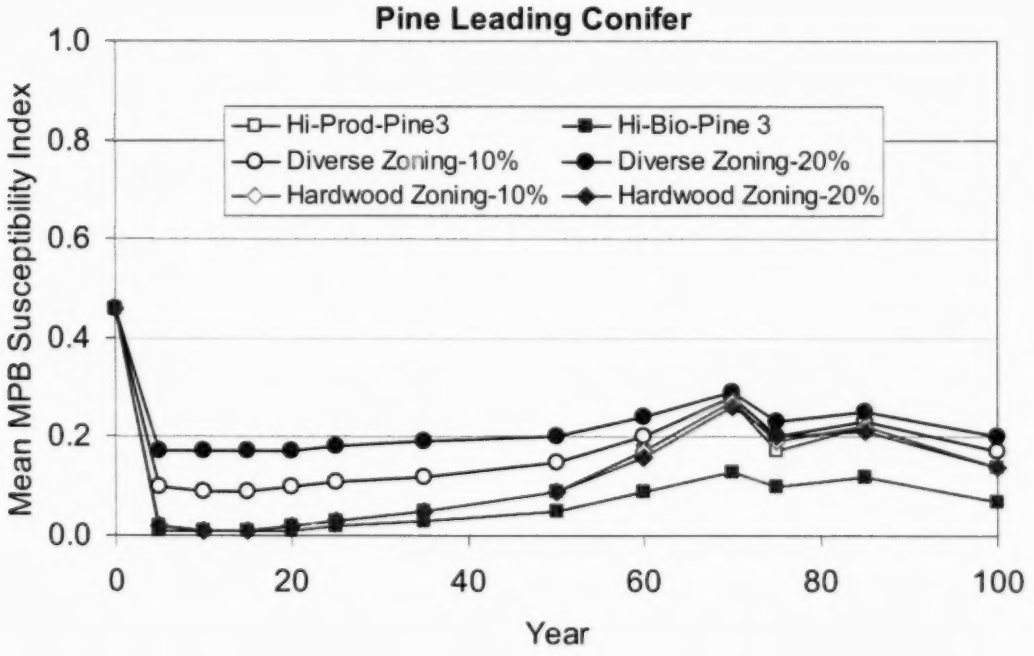

Figure 25. Mean landscape MPB Susceptibility index for the Pine Leading Conifer stratum during the 100-year planning horizon.

3.2.3 *Spatial bird models*

Bird Models

Habitat models were developed for ten species using breeding bird survey data and habitat covariates derived from map-based inventory data (Table 9). The internal predictive accuracy of the models, as measured by AUC scores, ranged from 0.75 for Yellow Warbler to 0.87 for Least Flycatcher and Ovenbird, indicating that they have moderate to high accuracy. The models were considered to be adequate for use in the current time period within TFL 48. Clearly it is not possible to know how reliable the models are for making projections 100 years into the future and more validation work would be needed to increase confidence in the models for this purpose. Nonetheless, the models should be sufficient for short term projections and for longer term comparisons of general responses between species and scenarios.

Table 9. Coefficients and standard errors for logistic regression models. Statistically significant coefficients are shaded.

Variable	AMRE	LEFL	OVEN	RBGR	REVI	TOWA	WAVI	WETA	WTSP	YEWA
ELEV	-0.53	-14.018	6.593	-0.059	-1.106	-0.421	-7.091	-2.443	-3.75	-9.882
	-0.09	(1.97)*	-0.77	-0.01	-0.14	-0.07	-1.31	-0.44	-0.59	-1.65
N_VPINE	-0.143	-0.059	0.137	0.172	-0.154	-0.402	0.158	0.2	0.065	-0.101
	-1.39	-0.35	-0.91	-1.63	-0.84	(3.41)**	-1.81	-1.92	-0.72	-1.04
N_VCON	-0.457	-0.417	-0.506	-0.438	-0.446	0.888	-0.447	0.039	-0.58	-0.391
	(3.29)**	(1.98)*	(2.12)*	(2.06)*	-1.75	(6.02)**	(3.63)**	-0.34	(4.65)**	(2.99)**
N_VDEC	1.041	1.392	1.438	1.295	0.949	-1.36	0.958	0.948	1.579	0.9
	(6.43)**	(7.61)**	(8.53)**	(6.27)**	(6.35)**	(3.39)**	(3.85)**	(5.84)**	(5.18)**	(6.53)**
N_WATER	0.454	0.156	0.233	-0.307	-0.243	0.456	0.596	0.403	0.323	0.205
	-1.71	-0.48	-0.63	-0.77	-0.68	-1.85	(2.14)*	(2.04)*	-1.35	-0.83
N_NFOR	-0.006	-0.003	-0.003	-0.007	0.003	-0.025	0.005	-0.013	-0.004	-0.001
	-1.23	-0.53	-0.32	-0.77	-0.33	(3.33)**	-0.95	-1.8	-0.86	-0.22
N_NVEG	-0.003	0.011	0.01	0.003	0.004	-0.077	0.049	0.005	0.021	0.006
	-0.81	(2.65)**	-1.61	-0.63	-1	(4.63)**	(2.93)**	-1.14	(2.22)*	-1.43
Constant	-0.499	-1.347	-3.575	-2.23	-2.251	-0.832	1.051	-2.053	1.018	0.02
	-0.85	-1.48	(3.43)**	(3.07)**	(2.08)*	-1.23	-1.58	(3.25)**	-1.6	-0.03
Obs	2282	2282	2282	2282	2282	2282	2282	2282	2282	2282
AUC	0.78	0.87	0.87	0.85	0.81	0.85	0.77	0.76	0.79	0.75

Robust z statistics in parentheses: * significant at 5%; ** significant at 1%

The number of significant covariates ranges from one for Red-eyed Vireo to five for Townsend's Warbler. Several habitat covariates were important for more than one species. The volumes of deciduous and coniferous trees within a 400 m radius were the two most important predictor variables, being significant for ten and nine species, respectively. Deciduous volume was positively associated with nine of the ten species, the exception being Townsend's Warbler. Conversely, coniferous volume was only

positively associated with Townsend's Warbler and negatively associated with the other eight species. The proportion of non-vegetated habitat was the third most important variable, being significant for four of the ten species. The other four variables were significant for only one or two species.

Model Projections

The landscape scenario projections reflect, in part, the dependence of several indicator species on deciduous and coniferous volumes. Moreover, several species exhibit similar response patterns and we thus group them to facilitate the discussion. Differences among species within a group are noted when they are evident. Another broad pattern that emerged from the scenarios is the similarity between zoning scenarios based on a diversified reserve zoning approach (Hi-Diverse) vs. a hardwood reserve zoning approach (Hi-Hardwood). We thus organize our discussion along those lines as well and generally focus only on broad patterns. Likewise, non-zoning scenarios had similar, but slightly more accentuated patterns than Hi-Diverse scenarios. Two notable exceptions: 1) the Hi-Bio-Pine3 scenario was clearly the best non-zoning strategy for Townsend's Warbler and the worst for Yellow Warbler.

Group 1 – Least Flycatcher, Ovenbird, and Rose-breasted Grosbeak (Fig. 26 – LEFL). Species in this group all have positive associations with deciduous volume and weak negative associations with coniferous volume. The Hi-Diverse scenarios showed similar patterns with four broad phases. In the first 25 years, the landscape suitability index was relatively stable or slightly increasing, followed by a steep drop over the next 25 years – clearly reflecting the trajectory of deciduous tree volume in the landscape over the same period of time. Subsequently, there was another period of relative stability until year 75. The final 25 years resulted in a steep recovery of landscape suitability back to baseline conditions. The Hi-Hardwood scenarios, on the other hand, maintained or increased the suitability of the landscape by a modest amount and showed no dramatic departures in either direction. Evidently, setting aside 10% of hardwoods in reserves had an important beneficial effect in comparison to the Hi-Diverse scenarios, on the suitability of the THLB for this group of birds. Setting aside an additional 10% in hardwood reserves, however, did not result in a noticeable difference for this group.

Group 2 – American Redstart, Red-eyed Vireo, and Yellow Warbler (Fig. 26 – YEWA). Species in this group are strongly negatively influenced by coniferous volume and strongly positively influenced by deciduous volume. Under the Hi-Diverse scenarios, landscape suitability followed a similar pattern to group 1 species with the main exception being that between year 25 and 50 the decrease was much less pronounced and stopped just below the baseline level. Conversely, under the Hi-Hardwood scenarios, landscape suitability went up in the first 5 years and remained above the baseline at a near constant level for the remainder of the simulations. The Hi-Bio-Pine3 scenario, because of it focus on retention of mature structure (often conifers), had the lowest suitability index among all scenarios. This result should be interpreted with caution since the field data used to derive the model did not include sites located in variable retention stands.

Group 3 – Warbling Vireo and White-throated Sparrow (Fig. 26 – WAVI). Species in this group have similar habitat associations as those in group 2 with the addition that the amount of non-vegetated habitat also appears important, perhaps indicating an affinity to edges. These two species exhibited the least variability over time for both zoning types. In general, there was a modest tendency to increase between 50 and 100 years in the Hi-Diverse scenarios, whereas in the Hi-Hardwood scenarios the tendency starts earlier (25 years) and is a little more pronounced and varied by scenario type.

Group 4 – Townsend's Warbler (Fig. 26– TOWA). Townsend's Warbler is strongly influenced by increasing coniferous and pine volume and decreasing deciduous volume. Given these relationships, it was not surprising that the Hi-Bio-Pine3 scenario showed the best habitat suitability for this species. In the Hi-Diverse scenarios there was an initial increase followed by stability in landscape suitability in the first 20 years. This was followed by a moderate reduction and recovery to just above baseline conditions by year 50. Thereafter, landscape suitability steadily dropped until year 85 and then remained stable for the remaining 15 years. The pattern was similar for the first 25 years under the Hi-Hardwood scenarios. However, landscape suitability then decreased steadily until year 70 before recovering for the last 30 years.

Group 5 – Western Tanager (Fig. 26– WETA). Western Tanager is strongly influenced by increasing deciduous volume and to a lesser extent the presence of water. In all cases, the suitability of the landscape declined in the first 5 years, stabilized for the next 20 years, and, with the exception of the Hi-Hardwood scenarios, declined again until year 50. Thereafter, the Hi-Hardwood scenarios remained stable below the baseline while the other scenarios increased to just below the level of the HI-HARWOOD scenarios. The 20% hardwood reserve option provided the best strategy to mitigating the decline of landscape suitability for Western Tanager.

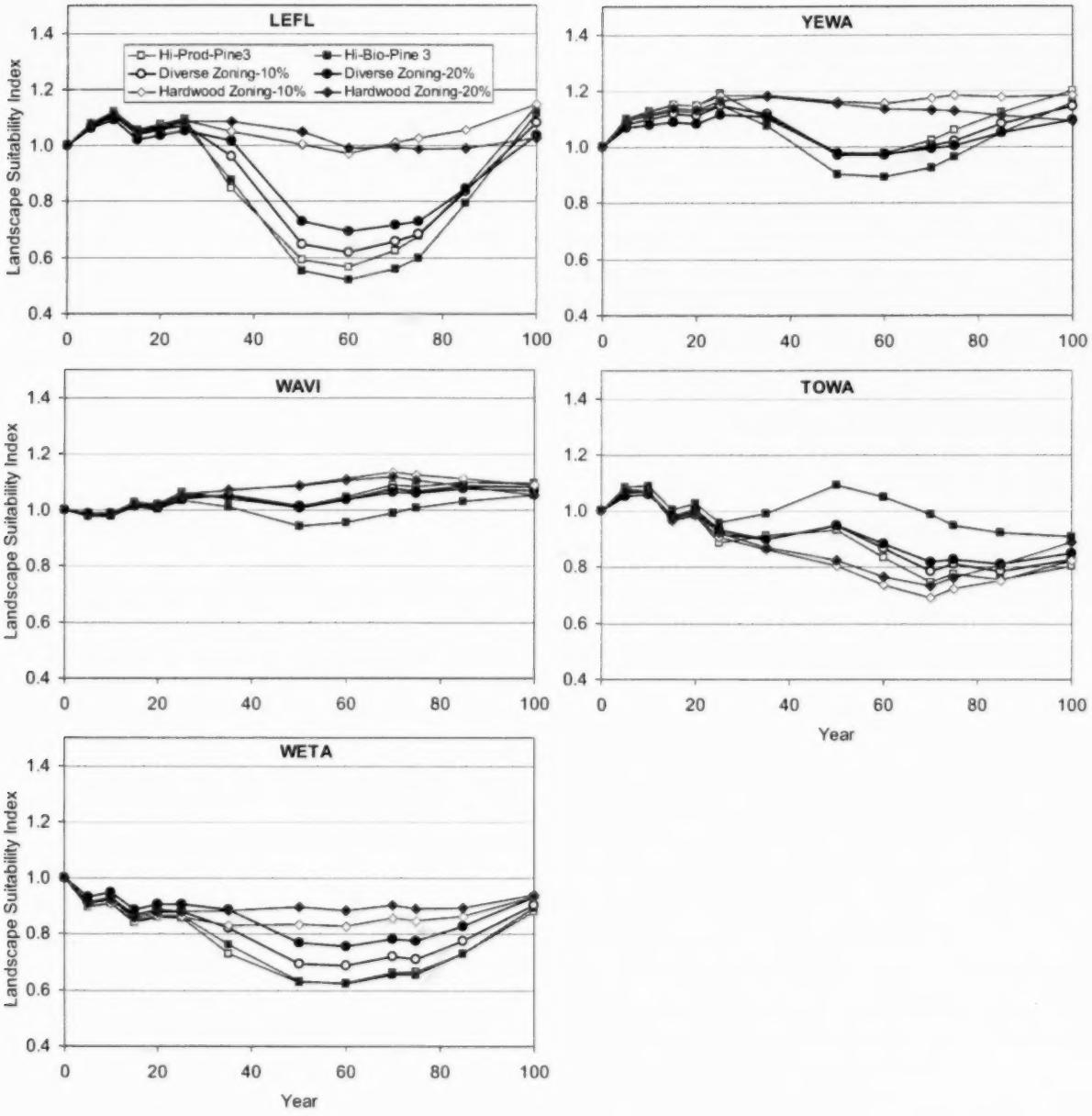

Figure 26. Landscape suitability projections under alternative scenarios for the Least Fly Catcher (LEFL), Yellow Warbler (YEWA), Warbling Vireo (WAVI), Townsend's Warbler (TOWA) and Western Tanager (WETA).

Implications

The bird models developed in this section were used as part of an evaluation of the ecological consequences of a number of landscape level MPB salvage/regeneration scenarios. The models describe the relationship between forest bird occurrences and habitat characteristics derived from forest inventory data and, as such, were fairly responsive to changes in the composition of the forest landscape as measured by the volume of broad forest types – attributes of the landscape that can be manipulated using management actions. Because it is not possible to test models into the future, we suggest that the models are best used in a comparative sense, for example, to rank landscape units or management scenarios. Several patterns emerged from the analysis of the zoning based scenarios:

- Most bird species appear to track the volume of deciduous and coniferous trees in the landscape. The volume of pine trees does not seem to exert an important effect.
- In some cases, the amount of non-vegetated habitat also appears significant, perhaps reflecting the importance of edges for some species. For example, non-vegetated areas, presumably adjacent to forests, appear to moderate the effects of volume and alter the trajectory of the scenarios for some of the species.
- In general, Hi-Hardwood scenarios had the most beneficial effects for most species, reflecting the relative importance of these habitat types for many species. This was especially evident in the middle years of the scenarios when landscape suitability generally declined for many species. Moreover, in most cases there was little difference between the 10% and 20% reserve options.
- In general, the two Hi-Diverse scenarios were similar except for Group 1 species where the 20% reserve option had a moderating effect on the decline which occurred between 25-50 years.
- Group 1 species experienced the most drastic reduction in landscape suitability amongst all groups. In particular, there was a very steep drop after year 25 with an almost equally steep recovery after year 75. The practice of reserving 10% of the THLB in reserves appears to have a major positive effect for this group.
- Group 2 species appeared to benefit in the short term (up to 35 years) under all zoning scenarios. Thereafter, there was a correction towards the baseline under the Hi-Diverse scenarios. Conversely, landscape suitability under Hi-Hardwood scenarios remained above the baseline for the duration of the simulations.
- Group 3 species were the least affected by any of the zoning scenarios.
- Townsend's Warbler (Group 4) was one of two species for which the suitability of the landscape declined in the long term – especially after year 50 for the Hi-Diverse scenarios and after 20 years for the Hi-Hardwood scenarios. The best case scenario in the long term for this species was the Hi- Bio-Pine3 scenario.
- Western Tanager (Group 5) also experienced a decline in landscape suitability and never fully recovered to baseline conditions. The Hi-Hardwood scenarios were the most effective at mitigating losses of habitat supply.

4 Conclusions

4.1 Potential impacts of mountain pine beetle in Northeastern BC forests

Upwards of 41% of the total productive landbase within TFL 48 was determined to be susceptible to MPB attack based on pine contents and age distributions within the present inventory. If the landbase were subjected to low-level attack (approximately 50% of susceptible stands), the analysis presented here suggests the impacts for both timber harvest and biodiversity indicators would be relatively small given the diversity of forest types within the TFL. However, a high-level of attack (100% of susceptible stands) would have a substantial impact primarily on pine-leading stand types, but also indirectly on other stand types which would have to absorb much of the harvesting activity in the interim period (20-70 years) following the initial attack.

4.1.1 Stand-level impacts

At the stand-level, MPB-attacked stands suffered varying losses of merchantable volume following attack depending on initial age class, pine content and secondary species. Losses were greatest in mature stands (> 80 years old) with high pine content; however, even younger stands (age 40-80) showed long-term reductions in merchantable volume related to reduced stocking levels.

With respect to biodiversity indicators, MPB attack typically led to extended periods of time with few large snags following the loss of MPB-killed snags, particularly in stands with high initial pine contents. Measures of large live structure were less impacted by MPB as unsalvaged stands tended to retain enough large live stems to maintain the index at relatively high levels.

Long-term patterns of ecosystem carbon storage were affected by MPB in a similar way to merchantable volume, but the relative impact of MPB attack was less pronounced as live biomass typically represents less than half of total carbon storage in these ecosystems. It was evident, however, that ecosystem carbon storage could be improved by as much as 20% over the long-term by salvaging and regenerating MPB-killed stands.

4.1.2 Landscape-scale impacts

At the landscape scale, with exception of pine-leading stand types, the impact of a high level of MPB attack on landscape scale biodiversity indices was largely a byproduct of salvage harvesting and the associated shift in harvesting patterns required to maintain harvest levels following the salvage period. The Wet Mountain region dominated by ESSFwc stand types provided for much of the harvest during the post-salvage period until salvaged stands became available for harvest around year 70. This shift in harvesting resulted in a substantial loss of mature forest within this region. For example, the mean landscape Large Live Structure and Snag indices in the High Elevation Spruce Balsam stratum dropped by as much as 59% and 56% respectively, by the end of the 100-year planning horizon relative to pre-attack conditions. Deciduous and mixedwood stands within the Boreal Plains region of TFL 48 were also subjected to increased post-salvage harvest pressure in most scenarios examined. Impacts to indicators of

biodiversity in these forest types were greatest between year 25 and 75 of the planning horizon, but varied with salvage strategy (See Section 4.2.2).

4.2 Opportunities for mitigating ecological impacts of salvage

4.2.1 Stand management options

Of the three alternative stand-level salvage options explored (**Biodiversity** – emphasis on retention of live structure, **Production** – emphasis on reestablishment of productive pine dominant stands, and **Risk Reduction** – emphasis on a shift towards the reestablishment of spruce-dominated stands), the Biodiversity option had the best overall performance. While it is not surprising that this option performed well with respect to the stand-level biodiversity indicators, it also performed reasonably well with respect to indices of merchantable volume, ecosystem carbon storage and, surprisingly, MPB susceptibility. In the case of the latter, it even equalled or reduced the long-term susceptibility of most salvaged stand types compared to the Risk Reduction option. This was related to the fact that the retained non-pine species generally accounted for a substantial proportion of the basal area in the subsequent developing stand.

Despite its good performance with respect to the stand-level indicators, the Hi-Bio-Pine3 scenario, which incorporated the Biodiversity stand management option (see Table 5), was among the worst for all of the landscape bird habitat suitability indices evaluated here, with exception of the Townsend's Warbler. As explained in Section 3.2.3, the main reason for its poor performance was the fact that it produced many stands with relatively high conifer volume, which is included as a negative term in many of the empirically derived bird models (see Table 9). It is not clear whether these birds are actively avoiding conifers (spruce in particular) or whether conifer volume is simply inversely correlated with hardwood volume. This issue requires further investigation. Clearly, many of the birds evaluated herein have a strong preference for deciduous-containing stand types and decisions regarding the application of the stand-level Biodiversity harvest option should take this into consideration (see Section 4.2.2).

While the Production option outperformed the others with respect to merchantable volume accumulation rates, it was consistently poor with respect to biodiversity indicators and typically produced stands with relatively high MPB susceptibility over the long-term. The Risk Reduction scenario was generally regarded as unnecessary considering the Biodiversity option performed equally well in reducing long-term MPB susceptibility.

4.2.2 Landscape management options

In evaluating the relative merit of alternative approaches to salvage and post-salvage harvesting, it is essential to consider both economic and ecological indicators. The best strategies from an ecological perspective will be of limited value of they are not economically viable.

The differences among the alternative salvage scenarios evaluated here on economic indicators were greatest during the salvage period (years 1-15). The Hi-Prod-Pine3 and

Hi-Hardwood-10% scenarios provided roughly 41% and 29% higher salvage harvest volumes relative to the Hi-Diverse-20% and Hi-Bio-Pine3 scenarios, respectively. The difference between harvest volumes in the highest (Hi-Prod-Pine3) and lowest Hi-Bio-Pine3) scenarios during the post-salvage period was 26%, but both of the 10% zoning scenarios were within 8%. Average profitability per cubic meter of harvested volume was similar among scenarios with the zoning scenarios having a slight advantage due to small reductions in road networks required for harvesting.

The relative rating of the alternative management scenarios with respect to the biodiversity indicators evaluated here was essentially the inverse of that reported for economic indicators, with the Hi-Bio-Pine3 and 20% zoning scenarios among the best and the Hi-Prod-Pine3 consistently the worst. There were some important differences between the Hi-Bio-Pine3 scenario and the different zoning scenarios, depending on which biodiversity indicators were considered. As discussed above, the Hi-Bio-Pine3 performed poorly with respect to most of the bird landscape habitat suitability indices. The Hardwood Zoning scenarios were by far the best for bird habitat, but there was only modest improvements by increasing the level of retention from 10 to 20%. In contrast, the Diverse Zoning scenarios were substantially better than the Hardwood Zoning scenarios with respect to general indicators of mature forest conditions.

Overall, these findings highlight the importance of compromise in developing long-term MPB salvage strategies. The zoning strategies with 10% retention are perhaps the best all-around choice. Decisions with respect to which forest types should be reserved, and to what level, should be made in the context of regional planning priorities. Further, there may be opportunities for varying retention levels throughout the planning horizon to improve outcomes. Lastly, it would also be wise to balance the use of stand management options focused on the retention and recruitment of mature structure with those designed for enhancing productivity.

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7 Appendices

Appendix 1. Detailed description of analysis units, MPB attack assumptions, and salvage/harvest options.

A1. Description of Analysis Units

The details used to simulate each of the natural stand analysis units in FORECAST, including transition pathways following MPB attack and harvest, are described in Table A1.

Table A1. A description of the natural stand analysis units. The 'attack' column indicates the MPB analysis unit to which the stand will transition when attacked. Transition pathways following MPB attack depend on age class which is why each MPB susceptible AU is shown twice. These transition pathways are the same for each of the 3 MPB attack intensities. However, there is a unique set of MPB AUs (with the same ID but stored in different file) for each attack intensity.

FORECAST AU	AC*	Description	Dataset	SI	Density	Sp1	Sp2	Sp3	Sp1%	Sp2%	Sp3%	Attack	Harvest
11110		Spruce low	ESSF	9	1500	Se	Bl		75	25		na	31110
11120		Spruce med/good	SBS	17	2000	Sx	Pl	At	70	15	15	na	31120
11210		Subalpine fir	ESSF	8	1600	Bl	Se		75	25		na	31210
11310		Deciduous	BWBS	16	3000	At	Sx		90	10		na	31310
11510		Dec - mixedwood	BWBS	15	2500	At	Sx		65	35		na	31510
11610		Con - mixedwood	BWBS	15	2000	Sx	At		65	35		na	31610
12110	2	Spruce - pine low	ESSF	11	1600	Sx	Pl		65	35		22112	32110
12110	3	Spruce - pine low	ESSF	11	1600	Sx	Pl		65	35		22113	32110
12120	2	Spruce - pine med/good	SBS	17	2000	Sx	Pl		65	35		22122	32120
12120	3	Spruce - pine med/good	SBS	17	2000	Sx	Pl		65	35		22123	32120
12210	2	Subalpine fir - pine	ESSF	8	1600	Bl	Pl		65	35		22212	32210
12210	3	Subalpine fir - pine	ESSF	8	1600	Bl	Pl		65	35		22213	32210
12310	2	Dec - pine	SBS	14	2500	At	Pl		70	30		22312	32310
12310	3	Dec - pine	SBS	14	2500	At	Pl		70	30		22313	32310
13110	2	Med Pine - spruce low	ESSF	11	2000	Pl	Se		65	35		23112	33110
13110	3	Med Pine - spruce low	ESSF	11	2000	Pl	Se		65	35		23113	33110
13120	2	Med Pine - spruce med/good	SBS	17	2000	Pl	Sx		65	35		23122	33120
13120	3	Med Pine - spruce med/good	SBS	17	2000	Pl	Sx		65	35		23123	33120
13210	2	Med Pine - subalpine fir	ESSF	11	2500	Pl	Bl		60	40		23212	33210

FORECAST AU	AC*	Description	Dataset	SI	Density	Sp1	Sp2	Sp3	Sp1%	Sp2%	Sp3%	Attack	Harvest
13210	3	Med Pine - subalpine fir	ESSF	11	2500	Pl	Bl		60	40		23213	33210
13310	2	Med Pine Dec low	SBS	12	2500	Pl	At		60	40		23312	33310
13310	3	Med Pine Dec low	SBS	12	2500	Pl	At		60	40		23313	33310
13320	2	Med Pine Dec med/good	SBS	17	2500	Pl	At		60	40		23322	33320
13320	3	Med Pine Dec med/good	SBS	17	2500	Pl	At		60	40		23323	33320
14110	2	High Pine - Spruce low	ESSF	11	2500	Pl	Se		85	15		24112	34110
14110	3	High Pine - Spruce low	ESSF	11	2500	Pl	Se		85	15		24113	34110
14120	2	High Pine - Spruce med/good	SBS	17	2500	Pl	Sx		85	15		24122	34120
14120	3	High Pine - Spruce med/good	SBS	17	2500	Pl	Sx		85	15		24123	34120
14210	2	High Pine - subalpine fir	ESSF	11	3000	Pl	Bl		85	15		24212	34210
14210	3	High Pine - subalpine fir	ESSF	11	3000	Pl	Bl		85	15		24213	34210
14310	2	High Pine - dec low	SBS	12	3000	Pl	At		85	15		24312	34310
14310	3	High Pine - dec low	SBS	12	3000	Pl	At		85	15		24313	34310
14320	2	High Pine - dec med/good	SBS	17	3000	Pl	At		85	15		24322	34320
14320	3	High Pine - dec med/good	SBS	17	3000	Pl	At		85	15		24323	34320

*Age class is used to determine which MPB AU (2 in the first position of the AU code) a specific natural stand AU will transition to if it is attacked.

A2. Simulating mountain pine beetle attack

Three different severities (low, medium, and high) of MPB attack were simulated at the stand level using mortality estimates based on the ***MPB Sim*** model (Riel et al. 2003). The mortalities and subsequent regeneration assumptions are illustrated in Tables A2 and A3, respectively. Regeneration rates and delays are based on the number of regional field studies located in MPB-killed stands. The time for which dead pine remains viable for harvest after mortality (e.g., shelf-life) was estimated based on the following decay function designed to represent a maximum shelf-life of 15 years.

$$V_{(t)} = V_{(t-1)} - (V_{(t-1)} * a * e^{b*t})$$

where : V = Volume of viable dead pine, t = time since mortality, a = coefficient (0.0215), b = coefficient (0.157).

Table A2. Mortality estimates for each of the MPB susceptible stand AUs for the low, medium and high attack scenarios. The mortality is represented to occur over a 5 to 7 year period.

					low	Med	high	Year (%)				Year (%)				Year (%)			
FORECAST AU	Description	Sp1	Sp2	MPB Age	%Pl mort	%Pl mort	%Pl mort	1	3	5	7	1	3	5	7	1	3	5	7
22112	Spruce - pine low	Se	Pl	60	25%	50%	90%	7%	12%	7%		17%	28%	15%		31%	58%	54%	27%
22113	Spruce - pine low	Se	Pl	100	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
22122	Spruce - pine med/good	Sx	Pl	60	25%	50%	90%	7%	12%	7%		17%	28%	15%		31%	58%	54%	27%
22123	Spruce - pine med/good	Sx	Pl	100	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
22212	Subalpine fir - pine	Bl	Pl	60	25%	50%	90%	7%	12%	7%		17%	28%	15%		31%	58%	54%	27%
22213	Subalpine fir - pine	Bl	Pl	100	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
22312	Dec - pine	At	Pl	60	25%	50%	90%	7%	12%	7%		17%	28%	15%		31%	58%	54%	27%
22313	Dec - pine	At	Pl	100	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
23112	Med Pine - spruce low	Pl	Se	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
23113	Med Pine - spruce low	Pl	Se	100	28%	55%	99%	8%	14%	8%		19%	31%	17%		45%	75%	70%	65%
23122	Med Pine - spruce med/good	Pl	Sx	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
23123	Med Pine - spruce med/good	Pl	Sx	100	28%	55%	99%	8%	14%	8%		19%	31%	17%		35%	64%	59%	30%
23212	Med Pine -subalpine fir	Pl	Bl	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
23213	Med Pine -subalpine fir	Pl	Bl	100	28%	55%	99%	8%	14%	8%		19%	31%	17%		45%	75%	70%	65%
23312	Med Pine Dec low	Pl	At	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
23313	Med Pine Dec low	Pl	At	100	28%	55%	99%	8%	14%	8%		19%	31%	17%		35%	64%	59%	30%
23322	Med Pine Dec med/good	Pl	At	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
23323	Med Pine Dec med/good	Pl	At	100	28%	55%	99%	8%	14%	8%		19%	31%	17%		45%	75%	70%	65%
24112	High Pine - Spruce low	Pl	Se	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
24113	High Pine - Spruce low	Pl	Se	100	25%	50%	91%	8%	13%	8%		18%	29%	15%		32%	59%	54%	27%
24122	High Pine - Spruce med/good	Pl	Sx	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
24123	High Pine - Spruce med/good	Pl	Sx	100	25%	50%	91%	8%	13%	8%		18%	29%	15%		32%	59%	54%	27%
24212	High Pine - subalpine fir	Pl	Bl	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
24213	High Pine - subalpine fir	Pl	Bl	100	25%	50%	91%	8%	13%	8%		18%	29%	15%		32%	59%	54%	27%
24312	High Pine - dec low	Pl	At	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
24313	High Pine - dec low	Pl	At	100	25%	50%	91%	8%	13%	8%		18%	29%	15%		32%	59%	54%	27%
24322	High Pine - dec med/good	Pl	At	60	23%	45%	81%	7%	11%	7%		16%	26%	14%		25%	45%	45%	20%
24323	High Pine - dec med/good	Pl	At	100	25%	50%	91%	8%	13%	8%		18%	29%	15%		32%	59%	54%	27%

Table A3. Natural regeneration assumptions for unsalvaged MPB analysis units for the low, medium and high attack scenarios. Levels of Pl and non-Pl regeneration reflect mortality levels shown in Table A2 (e.g., high mortality = high regen).

								low	low	med	med	high	high	
AU	Description	Dataset	SI	From	Sp1	Sp2	MPB Age	Pl regen	Other regen	Pl regen	Other regen	Pl regen	Other regen	delay
22112	Spruce - pine low	ESSF	11	1211	Se	Pl	60	100	220	190	440	340	790	10
22113	Spruce - pine low	ESSF	11	1211	Se	Pl	100	90	200	170	400	304	710	10
22122	Spruce - pine med/good	SBS	17	1212	Sx	Pl	60	100	220	190	440	337	790	10
22123	Spruce - pine med/good	SBS	17	1212	Sx	Pl	100	90	200	170	400	304	710	10
22212	Subalpine fir - pine	ESSF	8	1221	Bl	Pl	60	100	220	190	440	337	790	10
22213	Subalpine fir - pine	ESSF	8	1221	Bl	Pl	100	90	200	170	400	304	710	10
22312	Dec - pine	SBS	14	1231	At	Pl	60	100	220	190	440	337	790	10
22313	Dec - pine	SBS	14	1,231	At	Pl	100	90	200	170	400	304	710	10
23112	Med Pine - spruce low	ESSF	11	1311	Pl	Se	60	170	120	340	230	608	410	10
23113	Med Pine - spruce low	ESSF	11	1311	Pl	Se	100	210	140	420	280	743	500	10
23122	Med Pine - spruce med/good	SBS	17	1312	Pl	Sx	60	170	120	340	230	608	410	10
23123	Med Pine - spruce med/good	SBS	17	1312	Pl	Sx	100	210	140	420	280	743	500	10
23212	Med Pine -subalpine fir	ESSF	11	1321	Pl	Bl	60	170	120	340	230	608	410	10
23213	Med Pine -subalpine fir	ESSF	11	1321	Pl	Bl	100	210	140	420	280	743	500	10
23312	Med Pine Dec low	SBS	12	1331	Pl	At	60	170	120	340	230	608	410	10
23313	Med Pine Dec low	SBS	12	1331	Pl	At	100	210	140	420	280	743	500	10
23322	Med Pine Dec med/good	SBS	17	1332	Pl	At	60	170	120	340	230	608	410	10
23323	Med Pine Dec med/good	SBS	17	1332	Pl	At	100	210	140	420	280	743	500	10
24112	High Pine - Spruce low	ESSF	11	1411	Pl	Se	60	260	0	510	60	911	110	10
24113	High Pine - Spruce low	ESSF	11	1411	Pl	Se	100	290	0	570	70	1020	120	10
24122	High Pine - Spruce med/good	SBS	17	1412	Pl	Sx	60	260	0	510	60	911	110	10
24123	High Pine - Spruce med/good	SBS	17	1412	Pl	Sx	100	290	0	570	70	1020	120	10
24212	High Pine - subalpine fir	ESSF	11	1421	Pl	Bl	60	260	0	510	60	911	110	10
24213	High Pine - subalpine fir	ESSF	11	1421	Pl	Bl	100	290	0	570	70	1020	120	10
24312	High Pine - dec low	SBS	12	1431	Pl	At	60	260	0	510	60	911	110	10
24313	High Pine - dec low	SBS	12	1431	Pl	At	100	290	0	570	70	1020	120	10
24322	High Pine - dec med/good	SBS	17	1432	Pl	At	60	260	0	510	60	911	110	10
24323	High Pine - dec med/good	SBS	17	1432	Pl	At	100	290	0	570	70	1020	120	10

A3. Salvage and Management objectives and options

Each natural stand has an associated default managed stand which was assigned in the absence of MPB attack. In the case where stands have been attacked, they are assigned management options based on three alternative management scenarios with different objectives including 1) maintaining structures relevant for **biodiversity**, 2) maximizing **productivity**, 3) reducing **risk** of future MPB outbreaks. In the case of the risk reduction and productivity themes, only suitable stands were salvaged with targeted management, all others will be assigned to a default harvest AU.

Table A4 shows the specific transition pathways for each of the salvaged MPB AUs. In cases where a particular analysis unit is deemed unsuitable for a particular type of management, default salvage options will be selected. Default salvage options assume a clearcut harvest followed by regeneration to the same species present at the time of salvage. If a stand is not selected for salvage it will remain on its current MPB curve (e.g., AU begins with '2'). Lastly, a description of the managed/salvaged AUs as simulated in FORECAST is included in Table A5.

Table A4. Transition pathways for each of the MPB AUs for each of the three landscape levels of MPB attack severity. Different transition pathways are shown for each of the three stand management objective scenarios. If a '0' is shown for a particular objective the stand reverts to the default salvage. The AU for the default salvage is shown in the table under the default column for each MPB attack level.

AU	Description	Transition pathways for salvaged MPB stands			
		Biodiversity	Productivity	Risk Reduction	Default
		1	2	3	0
22112	Spruce - pine low	321121	0	0	321100
22113	Spruce - pine low	321131	0	0	321100
22122	Spruce - pine med/good	321221	0	0	321200
22123	Spruce - pine med/good	321231	0	0	321200
22212	Subalpine fir - pine	322121	0	0	322100
22213	Subalpine fir - pine	322131	0	0	322100
22312	Dec – pine	323121	0	0	323100
22313	Dec – pine	323131	0	0	323100
23112	Med Pine - spruce low	331121	0	0	331100
23113	Med Pine - spruce low	331131	0	0	331100
23122	Med Pine - spruce med/good	331221	331202	0	331200
23123	Med Pine - spruce med/good	331231	331202	0	331200
23212	Med Pine -subalpine fir	332121	0	0	332100
23213	Med Pine -subalpine fir	332131	0	0	332100
23312	Med Pine Dec low	333121	0	0	333100
23313	Med Pine Dec low	333131	0	0	333100
23322	Med Pine Dec med/good	333221	333202	0	333200
23323	Med Pine Dec med/good	333231	333202	0	333200
24112	High Pine - Spruce low	341121	0	341103	341100

AU	Description	Transition pathways for salvaged MPB stands			
		Biodiversity	Productivity	Risk Reduction	Default
		1	2	3	0
24113	High Pine - Spruce low	341131	0	341103	341100
24122	High Pine - Spruce med/good	341221	341202	341203	341200
24123	High Pine - Spruce med/good	341231	341202	341203	341200
24212	High Pine - subalpine fir	342121	0	342103	342100
24213	High Pine - subalpine fir	342131	0	342103	342100
24312	High Pine - dec low	343121	0	343103	343100
24313	High Pine - dec low	343131	0	343103	343100
24322	High Pine - dec med/good	343221	343202	343203	343200
24323	High Pine - dec med/good	343231	343202	343203	343200

Table A5. Description of AUs for managed or salvaged stands. These AUs are not distinguished by MPB attack level. The 'From' column indicates the AU from which the stand transitioned prior to harvest or salvage.

AU	Description	Dataset	Type	Objective	Harv Age	From	% Ret*	Plant	NR Density	Sp1	Sp2	NR Sp	Sp1%	Sp2%
311100	Spruce low	ESSF	Harvested	Default	200	1111		1200	500	Se	Pl	Bl	75	25
311200	Spruce med/good	SBS	Harvested	Default	140	1112		1500	500	Sx	Pl	At	75	25
312100	Subalpine fir	ESSF	Harvested	Default	165	1121		1200	800	Se	Pl	Bl	85	15
313100	Deciduous	BWBS	Harvested	Default	100	1131		0	3000	At				
315100	Dec - mixedwood	BWBS	Harvested	Default	120	1151		500	2000	Sx		At	100	
316100	Con - mixedwood	BWBS	Harvested	Default	140	1161		1200	1000	Sx		At	100	
321100	Spruce - pine low	ESSF	Salvaged	Default	100	22110		1200		Sx	Pl		70	30
321121	Spruce - pine low-60	ESSF	Salvaged	Bio	60	22112	15	900	400	Se2		Pl		
321131	Spruce - pine low-100	ESSF	Salvaged	Bio	100	22113	15	900	400	Se2		Pl		
321200	Spruce - pine med/good	SBS	Salvaged	Default	100	22120		1500		Sx	Pl		70	30
321202	Spruce - pine med/good	SBS	Salvaged	Prod	100	22120		1500		Pl	Sx		75	25
321221	Spruce - pine med/good-60	SBS	Salvaged	Bio	60	22122	15	900	500	Sx2		Pl		
321231	Spruce - pine med/good-100	SBS	Salvaged	Bio	100	22123	15	900	500	Sx2		Pl		
322100	Subalpine fir - pine	ESSF	Salvaged	Default	100	22210		1200	500	Sx	Pl	Bl		
322121	Subalpine fir - pine-60	ESSF	Salvaged	Bio	100	22212	15	900	250,250	Sx		Pl,Bl2		
322131	Subalpine fir - pine-	ESSF	Salvaged	Bio	100	22213	15	900	250,250	Sx		Pl,Bl2		

AU	Description	Dataset	Type	Objective	Harv Age	From	% Ret*	Plant	NR Density	Sp1	Sp2	NR Sp	Sp1%	Sp2%
	100													
323100	Dec - pine	SBS	Salvaged	Default	60	22310		600	2500	Sx	Pl	At	50	50
323121	Dec - pine-60	SBS	Salvaged	Bio	60	22312	15	500	1500	Sx	Pl	At2	50	50
323131	Dec - pine-100	SBS	Salvaged	Bio	100	22313	15	500	1500	Sx	Pl	At2	50	50
331100	Med Pine - spruce low	ESSF	Salvaged	Default	100	23110		1500		Se	Pl		50	50
331121	Med Pine - spruce low-60	ESSF	Salvaged	Bio	60	23112	20	900	500	Se2		Pl		
331131	Med Pine - spruce low-100	ESSF	Salvaged	Bio	100	23113	20	900	500	Se2		Pl		
331200	Med Pine - spruce med/good	SBS	Salvaged	Default	100	23120		1500		Sx	Pl		50	50
331202	Med Pine - spruce med/good	SBS	Salvaged	Prod	100	23120		1500		Pl	Sx		75	25
331221	Med Pine - spruce med/good-60	SBS	Salvaged	Bio	100	23122	30	900	500	Sx2		Pl		
331231	Med Pine - spruce med/good-100	SBS	Salvaged	Bio	100	23123	30	900	500	Sx2		Pl		
332100	Med Pine - subalpine fir	ESSF	Salvaged	Default	100	23210		1500	400	Se	Pl	Bl	50	50
332121	Med Pine - subalpine fir-60	ESSF	Salvaged	Bio	60	23212	20	900	300, 200	Se		Pl,Bl2		
332131	Med Pine - subalpine fir-100	ESSF	Salvaged	Bio	100	23213	20	900	300, 200	Se		Pl,Bl2		
333100	Med Pine Dec low	SBS	Salvaged	Default	60	23310		1000	1500	Sx	Pl	At	50	50
333121	Med Pine Dec low-60	SBS	Salvaged	Bio	60	23312	20	750	1000	Sx	Pl	At2	50	50
333131	Med Pine Dec low-100	SBS	Salvaged	Bio	100	23313	20	750	1000	Sx	Pl	At2	50	50
333200	Med Pine Dec med/good	SBS	Salvaged	Default	60	23320		1000	1500	Sx	Pl	At	50	50
333202	Med Pine Dec med/good	SBS	Salvaged	Prod	60	23320		1500	750	Pl	Sx	At	75	25
333221	Med Pine Dec med/good-60	SBS	Salvaged	Bio	60	23322	20	750	1000	Sx	Pl	At2	50	50
333231	Med Pine Dec med/good-100	SBS	Salvaged	Bio	100	23323	20	750	1000	Sx	Pl	At2	50	50
341100	High Pine - Spruce low	ESSF	Salvaged	Default	100	24110		1500		Pl	Se		75	25
341103	High Pine - Spruce low	ESSF	Salvaged	Risk	100	24110		1500		Se	Pl		80	20
341121	High Pine - Spruce low-60	ESSF	Salvaged	Bio	60	24112	60	800	750	Se2		Pl		
341131	High Pine - Spruce low-	ESSF	Salvaged	Bio	100	24113	60	800	750	Se2		Pl		

AU	Description	Dataset	Type	Objective	Harv Age	From	% Ret*	Plant	NR Density	Sp1	Sp2	NR Sp	Sp1%	Sp2%
	100													
341200	High Pine - Spruce med/good	SBS	Salvaged	Default	100	24120		1500		Pl	Sx		75	25
341202	High Pine - Spruce med/good	SBS	Salvaged	Prod	100	24120		1500		Pl	Sx		75	25
341203	High Pine - Spruce med/good	SBS	Salvaged	Risk	100	24120		1500		Sx	Pl		80	20
341221	High Pine - Spruce med/good-60	SBS	Salvaged	Bio	60	24122	60	900	750	Sx2		Pl		
341231	High Pine - Spruce med/good-100	SBS	Salvaged	Bio	100	24123	60	900	750	Sx2		Pl		
342100	High Pine - subalpine fir	ESSF	Salvaged	Default	100	24210		1500	250	Pl	Se	Bl	75	25
342103	High Pine - subalpine fir	ESSF	Salvaged	Risk	100	24210		1500	250	Se	Pl	Bl	80	20
342121	High Pine - subalpine fir-60	ESSF	Salvaged	Bio	60	24212	60	900	500,250	Se		Pl,Bl2		
342131	High Pine - subalpine fir-100	ESSF	Salvaged	Bio	100	24213	60	900	500,250	Se		Pl,Bl2		
343100	High Pine - dec low	SBS	Salvaged	Default	100	24310		1000	1000	Pl	Sx	At	75	25
343103	High Pine - dec low	SBS	Salvaged	Risk	100	24310		1000	1000	Sx	Pl	At	80	20
343121	High Pine - dec low-60	SBS	Salvaged	Bio	60	24312	60	1000	1000	Pl	Sx	At2	50	50
343131	High Pine - dec low-100	SBS	Salvaged	Bio	100	24313	60	1000	1000	Pl	Sx	At2	50	50
343200	High Pine - dec med/good	SBS	Salvaged	Default	100	24320		1000	1500	Pl	Sx	At	75	25
343202	High Pine - dec med/good	SBS	Salvaged	Prod	100	24320		1500	500	Pl	Sx	At	75	25
343203	High Pine - dec med/good	SBS	Salvaged	Risk	100	24320		1000	1500	Sx	Pl	At	80	20
343221	High Pine - dec med/good-60	SBS	Salvaged	Bio	60	24322	60	1000	750	Pl	Sx	At2	50	50
343231	High Pine - dec med/good-100	SBS	Salvaged	Bio	100	24323	60	1000	750	Pl	Sx	At2	50	50

* % Retention refers to the percent of non-pine tree species that were retained on the site during salvage to achieve an area-based, stand-level target of approximately 10% retention.

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